



Improved management based on stock identification of eastern and western Baltic cod

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DTU Aqua Report No. 265-2013

By Karin Hüsey, Francois Bastardie,
Margit Eero, Jakob Hemmer-Hansen,
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Danmark og EU investerer i bæredygtigt fiskeri og akvakultur

Projektet er støttet af Fødevareministeriet og EU

Ministeriet for Fødevarer,
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1. EXECUTIVE SUMMARY

The objective of this project was to establish an empirically founded knowledge base for the sustainable exploitation of the western Baltic cod stock by including the complex stock structure and migration patterns.

Stock mapping: Extensive immigration of “Eastern” cod into the Arkona Basin (SD 24) within the “Western” cod’s management unit was documented using high-powered genetic tools. The majority (91%) of all spawning fish caught in SD 24 in 2011 were “Eastern” cod and only 9% were from the “Western” stock. The results suggest that the stock structure in the Arkona Basin is highly influenced by mixing of genetically separate stocks.

Trends in mixing: Since the 1980’s where cod in SD 24 consisted primarily of “Western” type, the proportion of “Eastern” cod has increased, particularly since 2005. Throughout that period, the immigration of “Eastern” cod into SD 24 consisted primarily of adult, older fish. The changes in biological characteristics (mean size at age, condition and maturity) observed in that area since 2005 are thus a direct consequence of the extensive immigration of “Eastern” cod. As no seasonal signals in stock mixing were observed, the immigration is not associated with a change in “Eastern” cod’s spawning behaviour.

Management: The stock mixing proportions were successfully implemented in DTU Aqua’s modeling framework for management scenarios. “Eastern” immigrants into SD 24 lead the management procedure to advice for higher TACs that enhance the pressure on the fishing mortality level in SD 22. The fishing mortality level in SD 22 in this situation will need to be lowered i.e. by allocating more effort and catch from SD 22 to SD 24. Higher landings are expected if effort is re-directed/re-allocated to SD 24, profiting from the “Eastern” immigrants. By lowering the fishing mortality in SD 22, the SSB in SD 22 is also preserved, which is assumed to be the main source of recruits for the whole “western” stock (i.e. SD 22 + SD 24).

In conclusion: Within the frame of this project we showed that substantial immigration “Eastern” cod into SD 24 has occurred and that these stock dynamics should be incorporated in evaluations of future management plans.

2. INTRODUCTION

Authors: Karin Hüsey, Margit Eero and Marie Storr-Paulsen

2.1 BACKGROUND

BALTIC COD

Cod are generally distributed throughout the Baltic Sea (Bagge et al., 1994). Historically, it has been assumed that two different cod stocks exist, which differ with respect to morphometric characteristics (growth, number of vertebrae, body shape, weight at size, otolith shape) as well as genetic variation (Bagge et al., 1994; Nielsen et al. 2003, 2005). Baltic cod reach maturity at a size of L_{50} = 30-38 cm and age of A_{50} = 2-3 years (smaller size and age in the eastern stock and in males compared to females) (Cardinale and Modin, 1999). After maturation the cod undertake specific migrations towards their spawning grounds, which are found in the deeper Basins (western Baltic: Kiel Bay, Danish Straits and Arkona; eastern Baltic: Bornholm). Following hatching, the larvae migrate towards the surface where their primary food, zooplankton, is abundant. The larvae are drifting with the currents towards shallower areas where they settle as small juvenile fish. In these nursery areas they switch from pelagic to demersal prey and start their bottom dwelling life. Over the first two year of their life, juvenile cod seem to be rather stationary but move to successively deeper depths (Pihl and Ulmstrand, 1993).

As part of their seasonal cycle, adult cod undertake distinct and highly complex migrations after the onset of maturation, targeting specific feeding and spawning areas (Aro, 1989). Historic migration patterns (during the 1960's – 1980's), based on particularly tagging and recapture of individuals showed the following trends: The general direction of the spawning migrations in (SD 22) was towards the southern Kattegat and Danish Belts (Bagge, 1969; Otterlind, 1985). Cod in the eastern part of the western Baltic Sea, specifically the Arkona Basin (SD24), followed a quite different migration pattern. Small fish generally seemed to be rather stationary (Berner, 1967, 1974) while adult cod migrated both west and east, even east of the Bornholm Basin. These adult migrations were probably associated with spawning (Berner, 1967; Otterlind, 1985). Berner and Borrmann (1985) noted that cod tagged from January to April moved west while those tagged from May to August moved east, and those tagged from September to December tended to stay in the Arkona Basin. These migrations may, therefore indicate contributions of spawning components of both eastern and western Baltic cod stocks in the Arkona Basin.

The abundance of eastern Baltic cod substantially increased since 2007, after several decades of severe depletion. This was largely due to improved recruitment production, as well as due to improved compliance with TAC (Eero et al. 2012a). However, shortly after the recovery of the eastern Baltic cod, unexpected side effects became apparent. The eastern Baltic cod has not re-occupied its former wide distribution range in northeastern Baltic Sea, but remains concentrated in a limited area in the southern Baltic Sea, mainly in ICES SD 25 (Eero et al. 2012b) (Figure 1). The biomass of forage fish, i.e., sprat and herring, is historic low in this area, at least during parts of a

year, which in combination with increasing cod stock results in locally high predation mortality of forage fish and cannibalism of cod. In line with low prey availability, body weight and nutritional condition of cod drastically declined (Eero et al. 2012b). Cod biomass in the western Baltic Sea (SD 22-24) has increased since early 2000s, however recruitment in this area has been historic low and the last somewhat stronger year-class was recorded in 2003 (ICES WGBFAS 2012) (Figure 2). The increase in cod stock in the western Baltic is due to increased abundance of older cod (age 4+; Figure 3). The abundance of adult cod in the western Baltic Sea is currently at a highest observed level since 1970. This is not corresponding to the record high level of SSB due to substantially lower mean weights at age in recent years (see section for WP2 below). It is hypothesized that the older cod found in the western Baltic Sea are, at least partly, the eastern Baltic cod expanding its distribution area to the west, to release density dependence and food limitation in SD 25.

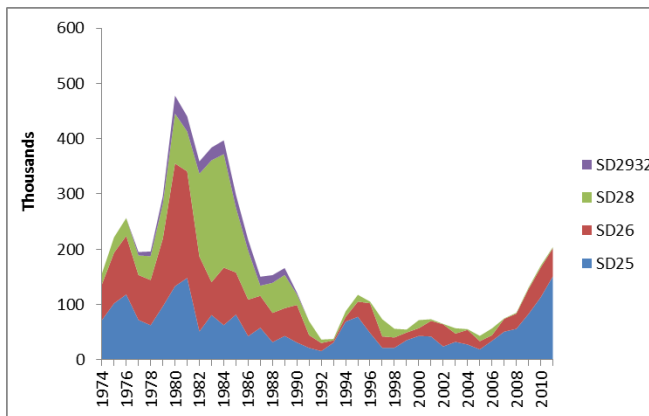


Figure 1. Abundance of adult (age 4+) cod in the eastern Baltic Sea by SD (Eero et al. 2012b)

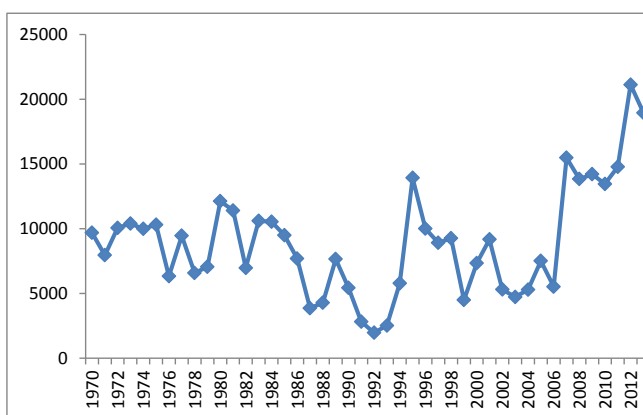


Figure 3. Abundance of adult (age 4+) cod in the western Baltic Sea (SD22-24)

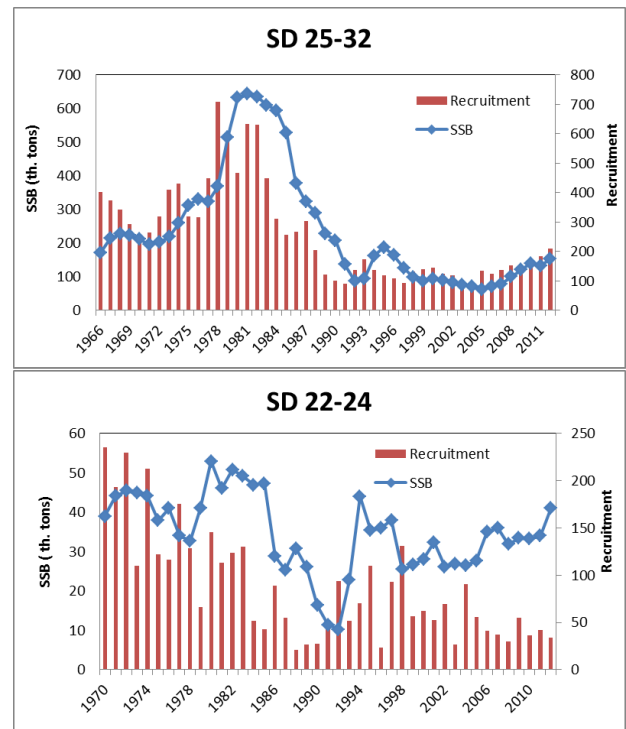


Figure 2. Spawning stock biomass (SSB) and recruitment of eastern (SD 25-32) and western (SD 22-24) Baltic cod (ICES WGBFAS 2013)

MANAGEMENT UNITS IN THE BALTIC SEA

The Baltic Sea has been partitioned into Subdivisions (SD) by ICES (Figure 4), depending on prevailing geographic and hydrological conditions. Traditionally, cod (*Gadus morhua*) in the Baltic Sea have been considered to be two separate stocks, one east of the island of Bornholm, the other from west of Bornholm to the Sound and the Danish Belts (Bagge et al., 1994). Baltic cod populations are assessed and managed as two distinct stocks, where SDs 25–32 are considered the geographical distribution of the eastern Baltic cod stock while SDs 22–24 are assigned to the western Baltic stock and fish are assigned to stock depending on the management area in which they were caught.

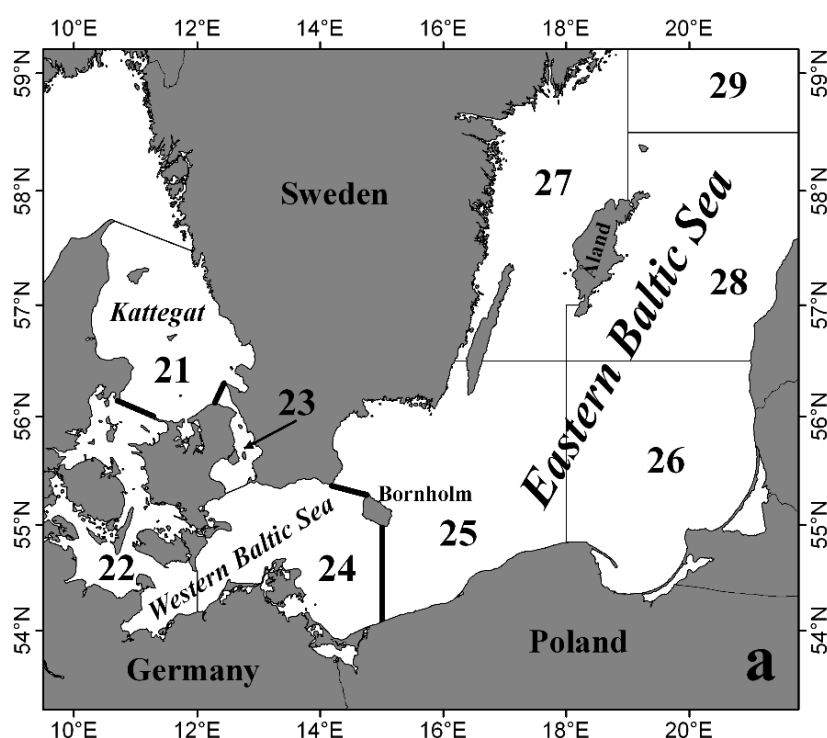


Figure 4. Map of the Baltic Sea area showing ICES Subdivisions (numbers) and management areas (Western Baltic Sea and Eastern Baltic Sea) enclosed by bold lines (from Hüsey, 2011)

THE FISHERY

The demersal fisheries in the western Baltic Sea are mainly conducted by trawlers and gill-netters. Most important cod fishing countries in the western Baltic Sea are Denmark and Germany. The analyses of distribution of Danish fishing effort in cod fisheries from VMS (Vessel Monitoring System) show that in SD 22 cod fishery largely takes place in the 1st quarter of a year, i.e during the spawning season of cod in this area (Bleil et al. 2009). During the rest of the year, fishing activities by trawlers in SD 22 are limited. In Arkona Basin (in SD 24) fishing activities are concentrated

during the 1st and 2nd quarter of a year. In the 3rd quarter, cod fishery is generally less intensive and taking place at the edges of the Arkona Basin in some years. In the 4th quarter, intensive cod fishery is taking place south of Bornholm, just around the border between SD 24 and 25 (Figure 5). In mid 2000s, cod fishery was also taking place in the western part of SD 24 (particularly in the 2nd and 4th quarter). Almost no fishing activity is recorded in this area in later years.

Fishing effort in the main fleet segments catching cod in the western Baltic has substantially declined in later years, e.g. effort in otter trawl segment in 2011 was 40 pct lower compared to 2006. In the eastern Baltic Sea, the effort has also declined since mid -2000s, and then stabilised or slightly increased in latest years (STECF 2012) (Figure 6). Fishing mortality of eastern Baltic cod has declined substantially since 2005 and is currently estimated close to the management plan target (0.3). Fishing mortality of younger age groups of cod in SD 22-24 has substantially declined since 2000s. The latest assessment estimates a high fishing mortality for older ages (especially for 5+), however these estimates are associated with larger uncertainties, partly due to spill-over of older cod from the eastern Baltic Sea (ICES WGBFAS 2013).

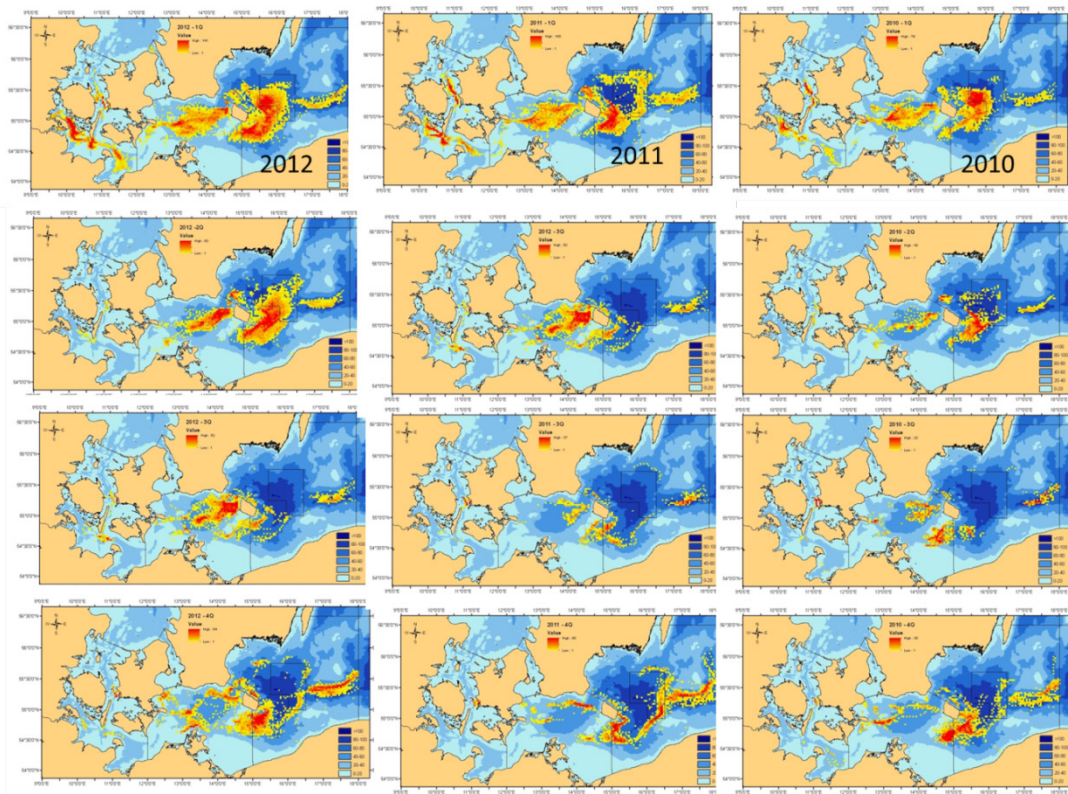


Figure 5: Distribution of fishing effort of the Danish demersal fleet targeting cod in the Baltic Sea, by year and quarter (the rows refer to 1-4 quarters, respectively)

Figure 5 continued

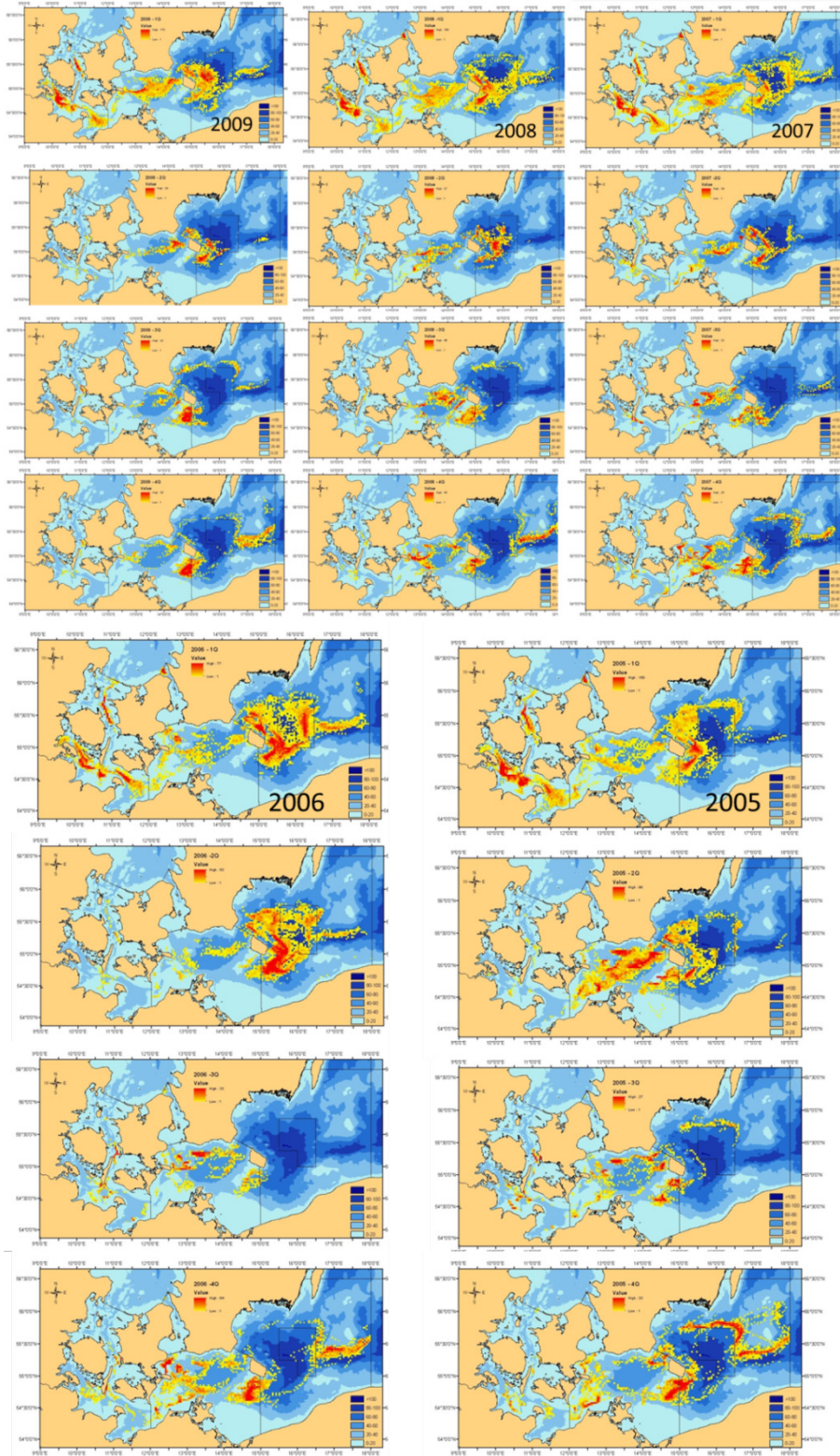


Figure 5. Distribution of fishing effort of the Danish demersal fleet targeting cod in the Baltic Sea, by year and quarter (the rows refer to 1-4 quarters, respectively)

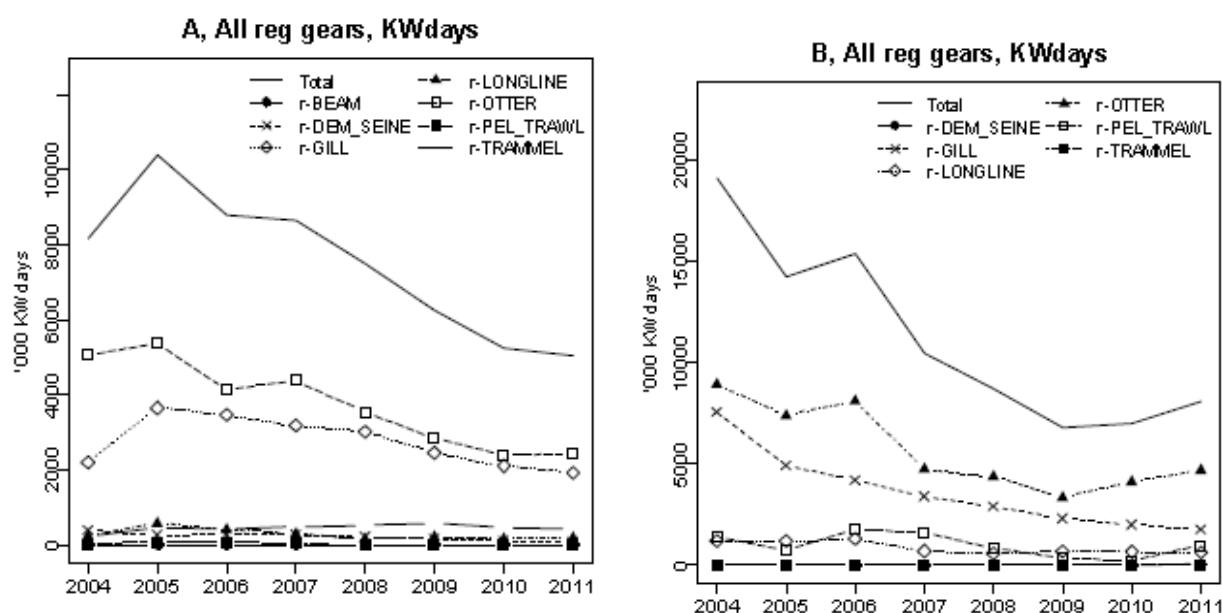


Figure 6. Trend in nominal effort by gear types in 2004-2011 (kW *days at sea) for regulated gears in the western (left panel) and eastern (right panel) Baltic Sea (STECF 2012)

INCENTIVE FOR THIS PROJECT:

The EU Commission has asked its scientific advisory committee (STECF) to evaluate the need for a revision of the present long term cod management plan (Bastardie et al., 2012; Nielsen et al., 2011; STECF 2010).

At present, the Fmsy (fishing mortality corresponding to maximum sustainable yield) estimated for the western Baltic cod is substantially lower (0.26) than the target fishing mortality defined in the cod management plan (0.6). Further, the stock structure in the management area of western Baltic cod (SD 22-24) is unclear, in particular due to the presumable expansion of the eastern Baltic cod distribution area to the western Baltic Sea in recent years.

A management plan that incorporates the complex stock structure in that region will provide the basis for an improved, sustainable exploitation of cod. A stable stock assessment is also essential for a future MSC certification of the two cod stocks.

2.2 OBJECTIVES

The objective of this project is to establish an empirically founded knowledge base for the sustainable exploitation of the western Baltic cod stock by including the complex stock structure and migration patterns. This objective is achieved by an interdisciplinary approach combining a range of data, historic and new samples, and different analytical approaches as well as modelling frameworks to:

1. Mapping the stock structures and migration patterns in the western and eastern Baltic cod stocks.
2. Testing of stock assessment model that incorporates differential fishing mortality for the stocks.
3. Evaluating the effects of different management plans (scenarios) in order to provide advice on a single management plan that results in sustainable exploitation of the cod stock in the western Baltic Sea with maximum catches.

2.3 PROJECT CONTENT AND STRUCTURE

This project consisted of a suit of working tasks, ranging from stock identification based on biological data over quantitative stock assessment taking into account new information on stock structure to evaluation of management plan scenarios. Stock identification was based on the coupling of two independent methods, 1) a qualitative identification of individual fish's stock affiliation based on genetic analyses and 2) a quantitative approach based on the analysis of otolith shapes. This approach allows estimation of the proportional composition of different stocks in a given sample. The extensive archive of historic cod otoliths back to the early 1980's present the opportunity to analyse stock mixing and estimate migration rates at different spatial as well as temporal scales. This information is incorporated into DTU Aqua's bio-economical fishery management models that integrate several stocks and fleets with geographic and seasonal trends in order to analyse management measures in relation to the European Commission's management plans. The results will during the coming years be integrated in ICES's advice and the Commissions management through relevant ICES and EU STECF working groups.

The work undertaken in this project was structured hierarchically in 4 work packages (WP), where the results from each WP are used in the next:

WP1: Collection of samples

WP2: Mapping of cod stocks in the western Baltic Sea

WP3: Quantitative evaluation of stock composition and trends in the western Baltic Sea

WP4: Analysis of management models

In the following, each of these WP's will be dealt with separately with a combined conclusions paragraph at the end.

3. WP1: COLLECTION OF SAMPLES

Authors: Karin Hüsey and Margit Eero

Three different sets of samples/data were used for this project: 1) Reference sample collection and 2) Historic otolith samples and 3) Stock assessment data. The objective of collecting a reference samples was to obtain fish during the spawning period of the different stock components, assuming that cod home for spawning (Svedäng et al., 2007). From these fish otoliths and tissue samples were collected to form a reference baseline for the subsequent analysis of archived otoliths and genetic composition of mixed samples. Otoliths from historic archives at DTU Aqua were selected to estimate the stock mixing during specific seasons and years as well as across most age classes. Finally, stock assessment data were collated in order to compare the obtained mixing rates achieved by otolith shape analysis with other stock-specific data available.

3.1 REFERENCE SAMPLE COLLECTION

In the following the procedures for sample selection and processing are described. An overview over the number of samples collected is given in Table 2.

Sampling procedures: Samples were collected from scientific research cruises with the RV “BALTICA” and RV “ALKOR”. In order to cover the main spawning seasons in all areas additional samplings were carried out from harbour landings (primarily Rødvig harbour). For the reference sample collection only individuals with maturity stages 4 - 6: “late spermatogenesis” to “spawning” (Tomkiewicz et al., 2002) were selected in order to ensure that the “true” stocks within an area were selected. These maturity stages correspond to stage 3: “spawning” in the Baltic International Trawl Survey (BITS) manual (WGBIFS, 2013) – for an overview of how the two staging systems correspond, see Table 1.

Table 1. Overview over maturity codes used for assessing maturity stages following the BITS manual (WKBIFS, 2013) and Tomkiewicz et al. (2002)

Maturity stage	BITS Code	Tomkiewicz et al.
VIRGIN	1	1 – 2
MATURING	2	3 - 5
SPAWNING	3	6 - 7
SPENT	4	8
RESTING	5	9 - 10

Sample location and time: For each stock, individuals were collected on the known spawning grounds during the spawning season. For the eastern Baltic cod the only spawning area at the moment is the Bornholm Basin (SD 25), with a spawning season from May to September (peak spawning season June/July). The main spawning grounds of the western Baltic cod are the Kiel Bay and the Danish Straits (SD 22) where the main spawning season is restricted to March/April. In the Arkona Basin (SD 24), efforts were made to cover both the Eastern and Western stocks' main spawning season, but in three consecutive years spawning individuals were only found in May/June and none in March/April. A summary of the collected reference samples is given in Table 2.

Table 2. Summary of the baseline reference sample (Spawning components)

Stock	Spawning component (SD)	Month	Sampling platform	N otoliths	N genetics
Western	23	March	HAVFISKEN	56	0
	22	March, April	Harbour	410	148
Eastern	25	June, July	BALTICA	1172	74
		August	ALKOR	362	14
Unknown	24	June, July	BALTICA	937	409
		May	Harbour	207	208

Sample preparation: Each fish was identified with an individual number. Capture location and date were recorded. Standard biological data were collected (length, sex, maturity stage). For each fish, a sample of fin-clip tissue was preserved in an Eppendorf vial filled with ethanol. Otoliths were removed and stored in paper bags following standard procedures. Both vials and otolith bags were marked with the fish's individual number.

Mixed stock samples for comparative analyses: In order to test the genetic and otolith shape discrimination procedures, samples from both spawning and non-spawning cod (representing samples from the fishery) were collected in SD 24. A total of 125 cod collected during the BALTICA and ALKOR cruises were used for this comparative analysis (also shown in Table 2).

Problems encountered: Despite many attempts in 2011, 2012 and 2013 it was not possible to obtain spawning or maturing fish in March/April in the Arkona Basin (SD 24). But from early May, spawning individuals were captured. All of these individuals spawning early in May were by genotyping identified to be Eastern Baltic cod (see paragraph on genetic analyses under WP2). This suggests that the Western Baltic cod stock is not spawning in SD 24 at present.

Only very small numbers of juveniles were obtained from discard samples in SD 24. This is in accordance with the very low recruitment of western Baltic cod estimated by the assessment working group (WGBIFS) (Figure 2).

3.2 HISTORIC OTOLITH SAMPLES

From the otolith archives of DTU Aqua historic samples from the mixing area in the Arkona Basin (SD 24) were retrieved. Samples originated primarily from Danish harbour collections and discard samples. The majority of the samples were from landings in the Danish harbours of Klintholm, Neksø, Rødvig, Rønne and Tejn. The samples were selected carefully to ensure adequate sample numbers within each quarter of the years and covering all possible age and size ranges. An overview over the mixed stock fisheries by year and quarter is given in Table 3. Within this project it was not possible to examine all available sampling years. In order to capture the dynamics within the last decade, where the stock size of the eastern Baltic cod has increased, we selected the years 2000, 2005, 2008, 2010 and 2011. For contrast, samples from the 1980's were also selected. As there were not enough samples within specific year in the samples from the 1980's, they were pooled.

Biological data associated with each fish/otolith was obtained from DTU Aqua's database BIA. Biological data consisted of length, size sorting, sex, maturity stage and age. These data are accompanied by information on catch location (ICES SD and statistical rectangle, longitude, latitude), catch date, trip type, station and fish nr. and landing harbour.

Table 3. Summary of historic samples used (mapping of mixing)

Year	Quarter	N otoliths
1980's	2	296
	3	329
2000	1	254
	2	74
	3	270
	4	256
2005	1	629
	2	352
	3	450
	4	391
2008	1	572
	2	350
	3	375
	4	542
2010	1	520
	2	423
	3	324
	4	618
2011	1	490
	2	322
	3	530
	4	526

3.3 STOCK ASSESSMENT DATA

In order to be able to examine changes in cod abundance and its biological parameters (e.g. mean weight, length, maturity) separately by sub-areas, time series of catches and biological data were compiled separately by ICES SD. The data analysed included:

- Catch in numbers and in weight
- Mean weight at age
- Mean length at age
- Nutritional condition of cod
- Catch per unit of effort (CPUE) from research surveys
- Proportion of cod by maturity stage

Biological data related to fisheries (catch numbers at age and mean weight at age in the catch) by SD were derived from ICES WGBFAS reports, back to 1985. BITS survey data was available from ICES database DATRAS. The data for mean length and mean weight, condition and maturity were derived from sampling during BITS surveys. The data were analysed separately for ICES SD 22 and 24, and SD 25 for comparison. Distribution of cod in the western Baltic Sea was examined using cpue data by individual stations.

3.4 CONCLUSIONS

All samples and data were collected as planned with the exception of the early spawning component and juveniles in SD 24. The lack of these samples did not hamper the outcome of this project, with the exception that it was not possible to carry out the analysis of where juveniles in SD 24 originate from.

Milestones:

M1. Collection of reference samples from the spawning stocks (Spawning seasons 2011 and 2012)

M2. Collection of samples from the fishery and of juveniles in SD 22-24 following the fishery (June 2012)

Status: *Accomplished*

4. WP2: MAPPING OF COD STOCKS IN THE WESTERN BALTIC SEA

This chapter consists of two different types of analyses: 1) A detailed analysis of biological stock data, and 2) Mapping of the stock's different genotypes and otolith shapes. The analysis of stock data in a more preliminary form was, together with the distribution of the catch data, the rationale for this project, while the mapping of genotypes and otolith shape form the basis for the subsequent analyses of stock mixing trends.

4.1 ANALYSES OF BIOLOGICAL STOCK DATA

Author: Margit Eero

DISTRIBUTION OF COD IN SD 22-24

Cod distribution within the western Baltic Sea was investigated by plotting haul by haul information from research surveys, available for the 1st and 4th quarter of the year. The data shows that young cod (ages 0 and 1) are generally more widely distributed with occasionally high abundances both in SD 22 and SD 24. In contrast, older cod are mainly found in SD 24 in recent years (Figure 7a-d).

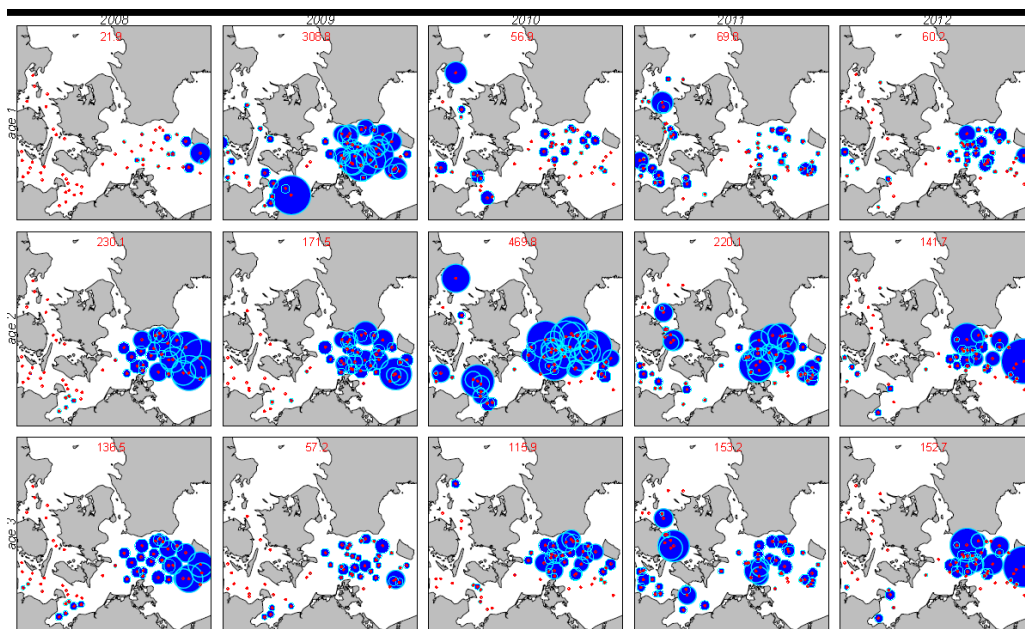


Figure 7a. Q1, ages 1-3, years 2008-2012

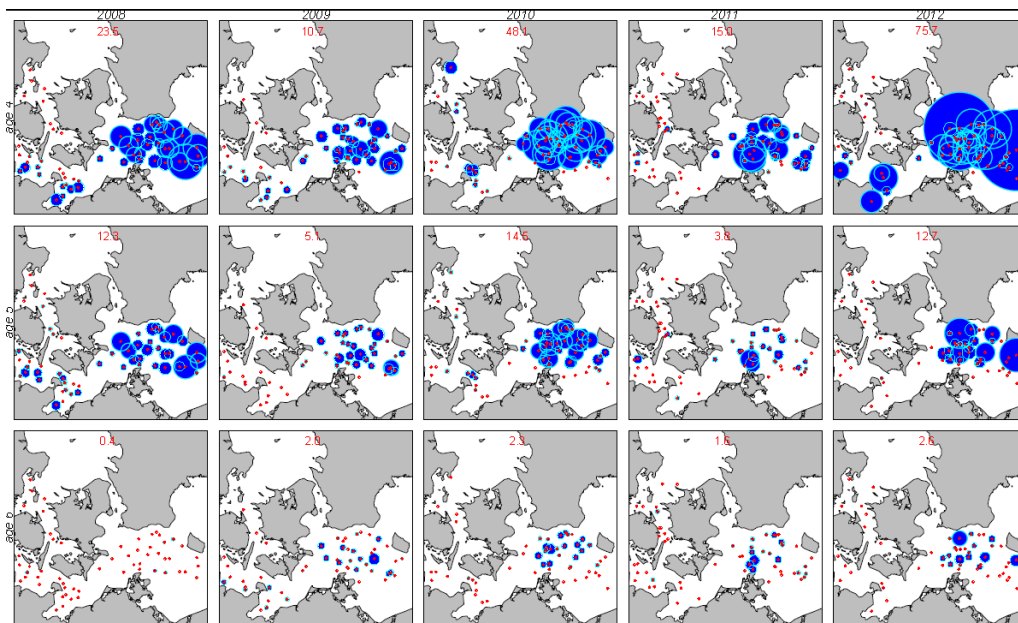


Figure 7b. Q1, ages 4-6, years 2008-2012

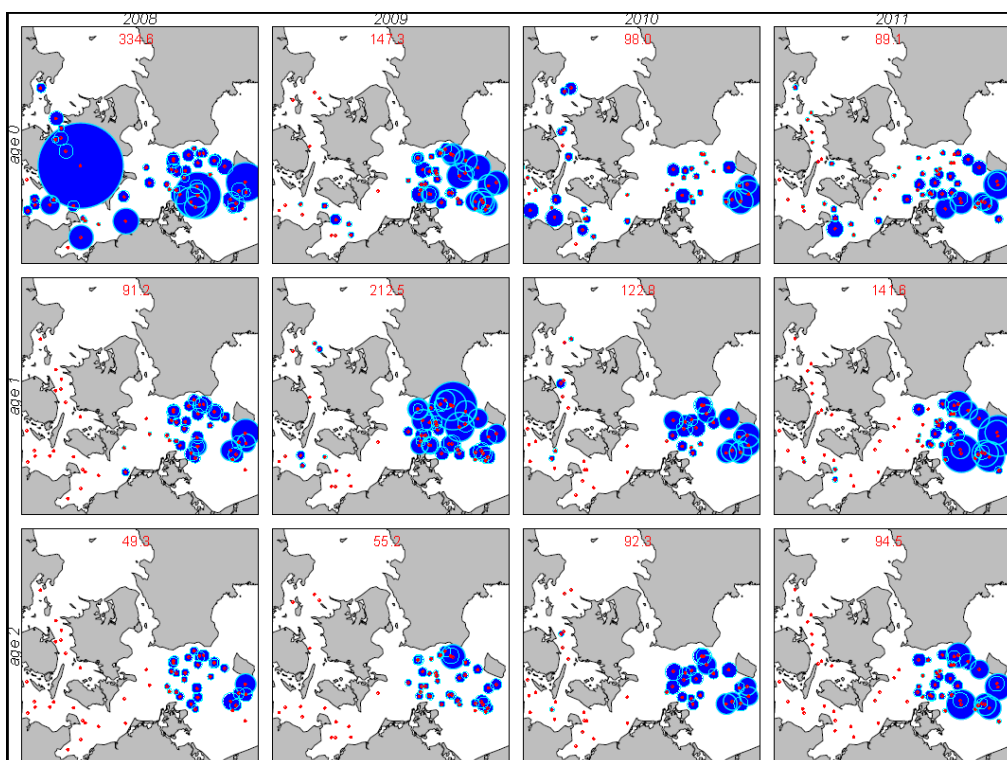


Figure 7c. Q4, ages 0-2, years 2008-2012

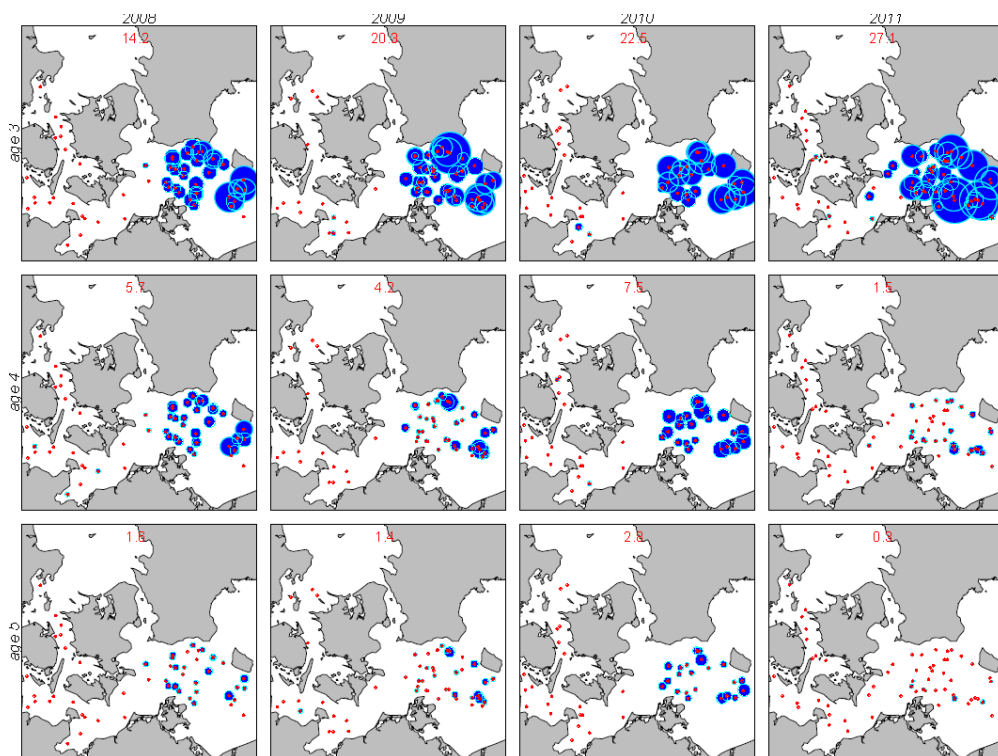


Figure 7d. Q4, ages 3-5, years 2008-2012

MEAN WEIGHT AND MEAN LENGTH AT AGE

Mean weight of younger cod (ages 1-3) in SDs 22, 24, and 25 has not changed substantially in the period from early 1990s to the present. Cod in a given age are generally heaviest in SD 22, followed by SD 24, and the lowest weights at age are recorded in SD25. This SD specific pattern is clearly visible for cod at ages up to 3 during the entire time series (Figure 8a) and for older ages up to the mid-2000s (Figure 8b). In about 2007, a drastic decline in mean weight at age of older (4+) cod is recorded in SD 24, to a similar level as in SD 25, where the mean weights also have declined in recent years. Cod at ages 4+ in SD 24 are currently weighting only about half as much as they did e.g. in the 1980s (Figure 8b).

Similar drastic decline is observed for mean length at age for older (4+) cod in SD 24 since 2007. The mean length of older cod in SD 24 is currently similar to that in SD 25, whereas in earlier years, the cod in SD 24 have been substantially larger in a given age than in SD 25 (Figure 9). Investigation of the variability in length at age for individual fish showed that the variation in length between individual fish in SD 24 in 2008-2012 (after the drastic decline in mean length at age) is much larger compared to 2000-2005 (before the drastic decline in mean length). In later period, larger proportions of smaller cod are observed, which were not recorded in the earlier period (Figure 10). The variability in length at age in SD 24 in 2008-2012 is similar to that in SD 25.

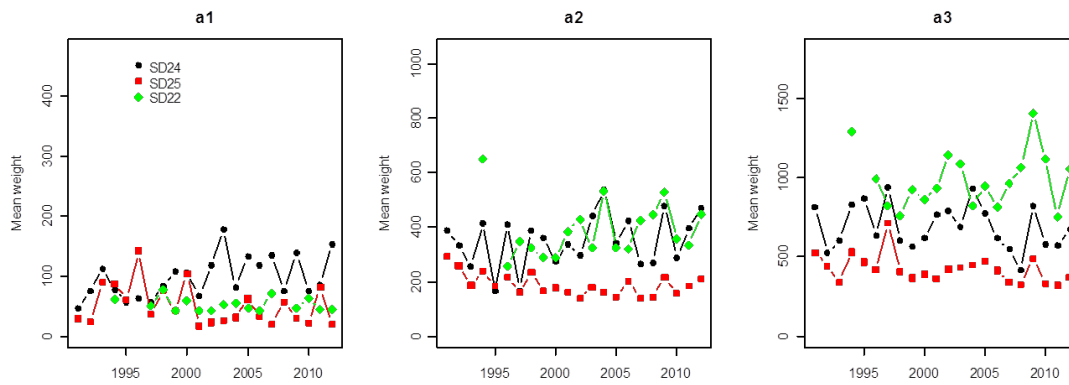


Figure 8a. Mean weight of cod at age 1-3, by SD, from BITS survey

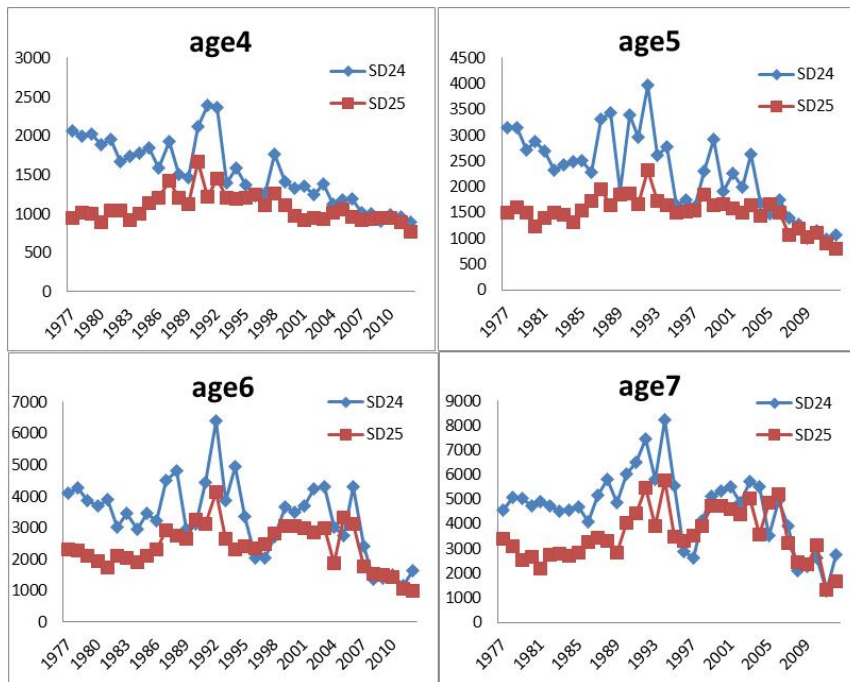


Figure 8b. Mean weight of cod at age 4-7, by SD, in commercial catches

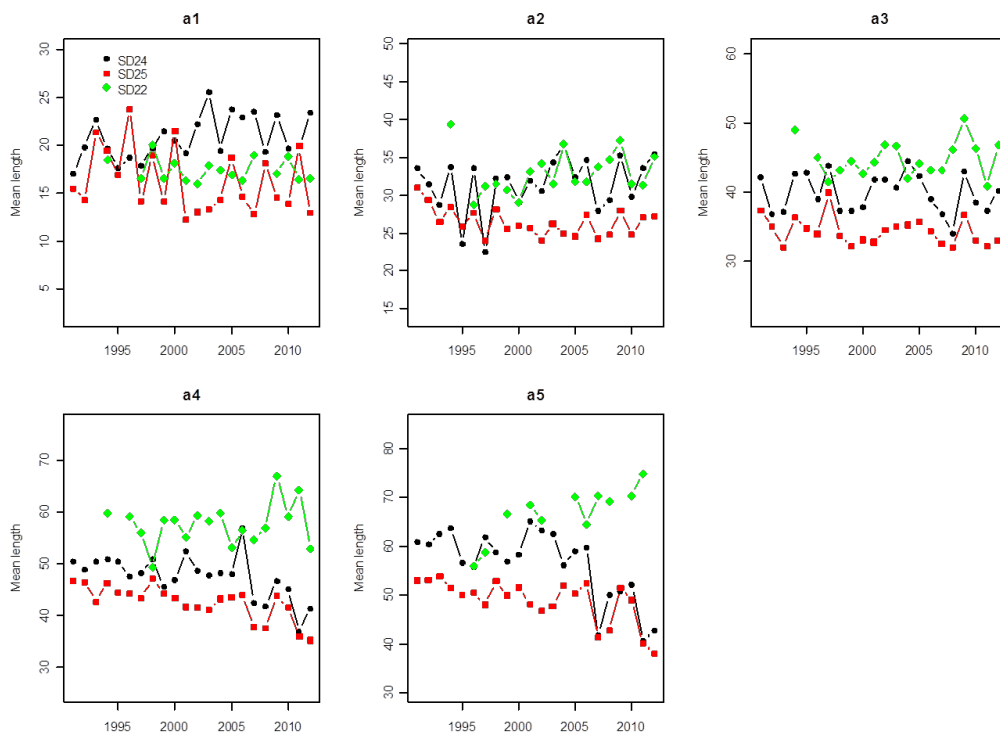


Figure 9. Mean length of cod at age, by SD

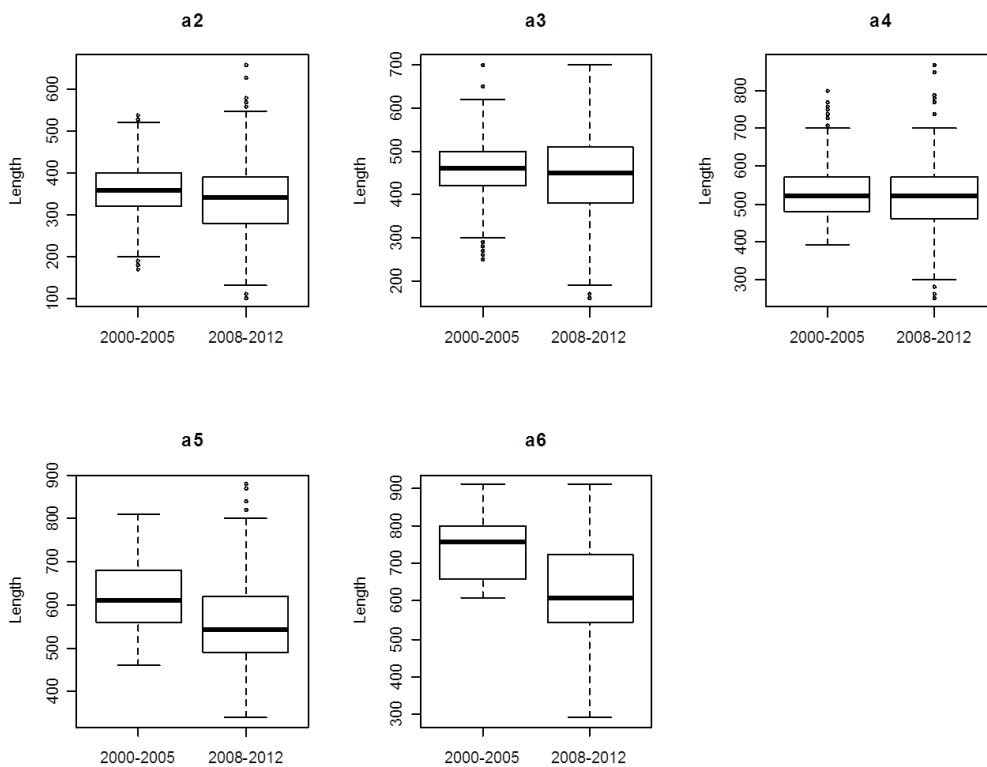


Figure 10. Variability in mean length of cod in SD 24 in two periods, before (2000-2005) and after (2008-2012) the drastic decline in mean weight at age of older (4+) cod

CONDITION OF COD

Analyses of Fulton condition show a declining trend in the mean condition of cod in SD 25 since the 1990s, especially for larger cod (40-60 cm in length). However, the proportion of cod at very poor condition (Fulton K < 0.8) has sharply increased in mid 2000s. Before 2005, there was hardly any cod in SD 25 with Fulton K below 0.8; while currently about 15% of larger cod found in SD 25 are in such poor condition (Figure 11). In SD 24, the proportion of larger cod (40-60cm in length) in poor condition (Fulton K < 0.8) has also increased since 2005, however it is still less than 5%, and thus much lower than the proportion of cod in low condition in SD 25. Also the mean condition of cod in SD 24 is currently higher than in SD 25. In SD 22, cod are generally in a better condition than in SD 24, 25 and no decline in condition since 1990s has been observed in SD 22.

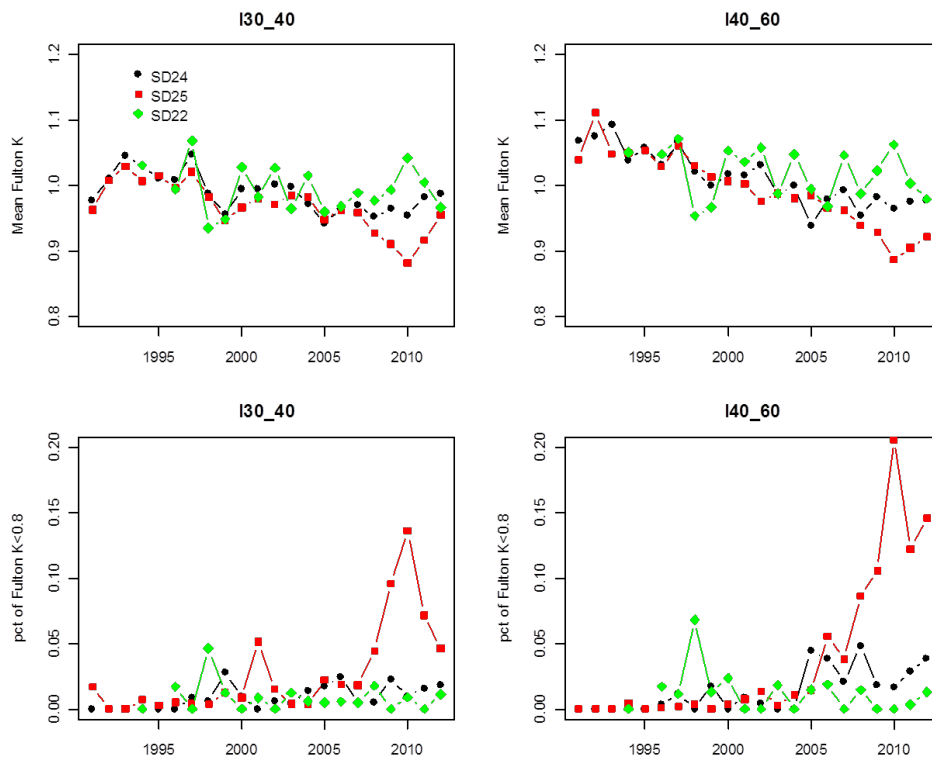


Figure 11. Mean condition of cod at 30-40 and 40-60 cm in length, by SD (upper panels) and proportion of cod with Fulton K below 0.8, by SD (lower panels)

MATURITY STAGES

It is known from literature that cod in SD 22 and in SD 24 have different spawning times (e.g. Bleil et al. 2009). In SD 22, cod are spawning earlier in a year than the Eastern stock, and that is reflected in BITS 1st quarter survey data with substantial proportion of cod at maturity stage 3 “spawning” according to WGBIFS (2013) in SD 22 (see Table 1). In SD 24 and 25, almost no spawning cod is found in quarter 1. The majority of cod above 30 cm in length in SD 24 and 25 are maturing cod, however a substantial proportion of cod in SD 24 (30–40%) is cod at maturity stage 5 (resting). This proportion has been stable since the mid-1990s (Figure 12). In contrast to SD 24, the proportion of cod recorded at maturity stage 5 is much lower in SD 25 (around 10%). No substantial changes in proportion of cod at different maturity stages has been recorded in recent years, in any of the three analysed SDs.

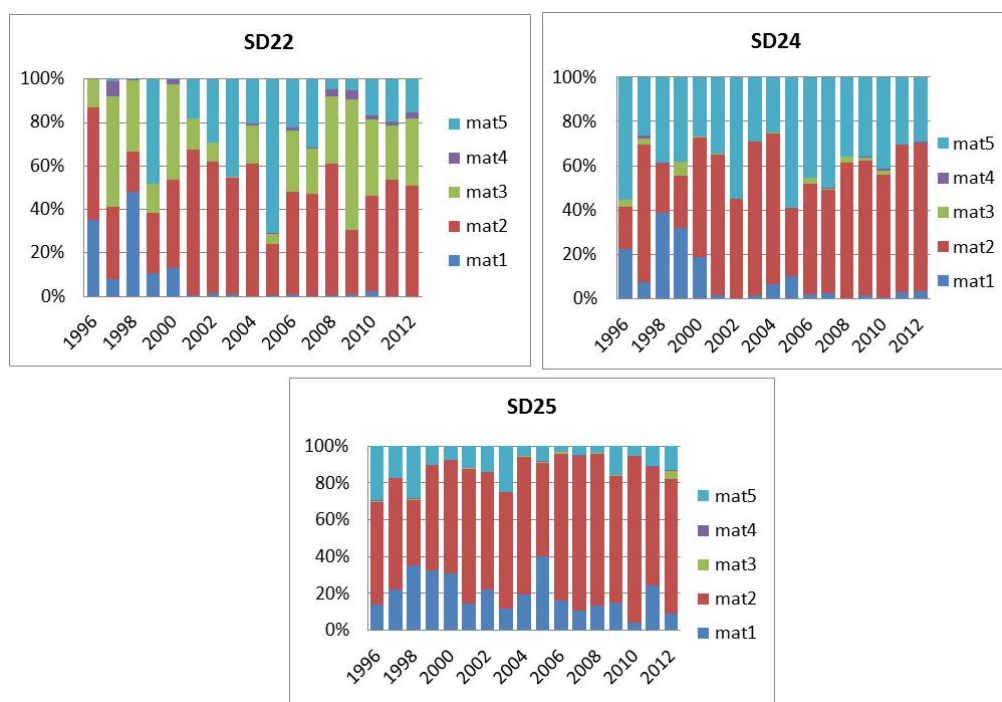


Figure 12. Proportion of cod (above 30cm in length) at different maturity stages (1-immature; 2-maturing; 3-spawning; 4-spent; 5-resting) in Q1 following the BITS manual (WGBIFS, 2013)

4.2 GENETIC ANALYSES

Author: Jakob Hemmer-Hansen

INTRODUCTION AND METHODS

Genetic analyses used Single Nucleotide Polymorphisms (SNPs), i.e. single base changes in the genetic code, as genetic markers. These molecular tags in the genome have been found to be particularly useful for determining the geographic origin of single fish (Nielsen et al. 2012). Initially, preliminary analyses were used to identify a panel of SNPs with particularly high statistical power for assigning individuals to either SD22 (western component) or SD25 (eastern component). These analyses were based on more than one thousand genetic markers, which were genotyped in reference samples collected in the spawning seasons in 2007. In addition, samples collected in spawning periods in 1996/1997 were used to assess temporal stability of assignment power with the chosen panel of markers. These markers all showed high population divergence between the eastern and western samples, and were chosen to give independent signals of population structuring. By selecting uncorrelated loci we avoided problems related to the inclusion of redundant information (see Pascou et al. 2008), which could potentially result in an overestimation of statistical power.

Following the selection of loci, samples collected in WP1 were genotyped for the identified panel of 39 loci (see Results), using SNPTYPETM assays on a Fluidigm BioMarkTM HD System. First, individual relationships based on genetic profiles were examined by principle component analysis. Subsequently, fish in spawning condition collected in WP1 from SD22 and SD25 were used as baselines for assignment of individuals from SD24.

Assignment was based on multi-locus genotypes using a Bayesian approach (Rannala and Mountain 1997) to calculate likelihoods for each individual in each of the two possible baseline populations (SD22 and SD25). All assignments were conducted through the programme GeneClass2 (Piry et al. 2004).

RESULTS

STATISTICAL POWER OF ASSIGNMENT METHOD

Initial analyses identified a panel of 39 genetic markers with high discriminatory power between eastern and western components. Using these 39 markers, all fish were assigned back to their own baseline component. In the western baseline sample, 95% of fish had a likelihood which was more than 10.000 times higher in the western than in the eastern sample. Similarly, 95% of the individuals from the eastern sample had a likelihood which was more than 1.700 times higher in the eastern than in the western baseline sample. The median difference between likelihoods to home vs.

away for all fish in the baseline samples were 1.1×10^9 for the western and 3.3×10^7 for the eastern baseline sample (see Figure 13a), demonstrating extremely high statistical power for individual assignment. Testing the panel in temporally replicated samples (Figure 13b) collected ten years previously showed similar high assignment power, illustrating temporal stability of assignment power with the selected panel of loci.

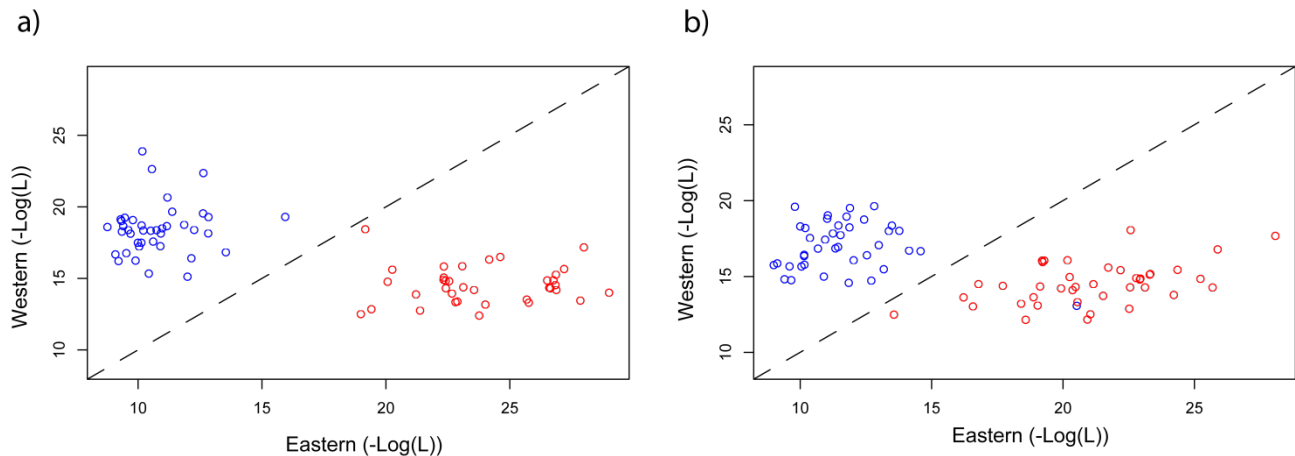


Figure 13. Assignment power of a panel of 39 genetic markers used in this study. Assignment of original reference samples used to select the markers is shown in a), while assignment of control samples used to assess temporal stability is shown in b). Eastern individuals are shown in blue and western individuals in red. Note that axis scale is negative Log(likelihood), i.e. a low number indicates a high likelihood. Dashed line shows equal likelihoods for eastern and western components. A clear separation of individuals from the two baseline samples indicates high assignment power. A single individual collected in the east is assigning to the western component with high certainty in the control samples. This individual most likely represented a migrant.

GENETIC PROFILES OF BASELINE AND ASSIGNMENT INDIVIDUALS

Principal component analyses of the 39 markers used for assignment showed a clear separation between eastern and western baseline samples (Figure 14). In addition, individuals collected in SD24 grouped either with eastern or western components, while only few fish had an intermediate genetic profile, suggesting that they could be hybrids between the two populations. The majority of individuals from SD24 grouped with the eastern component. However, particularly among the fish collected in June, a number of individuals also clearly grouped with the western component (Figure 14).

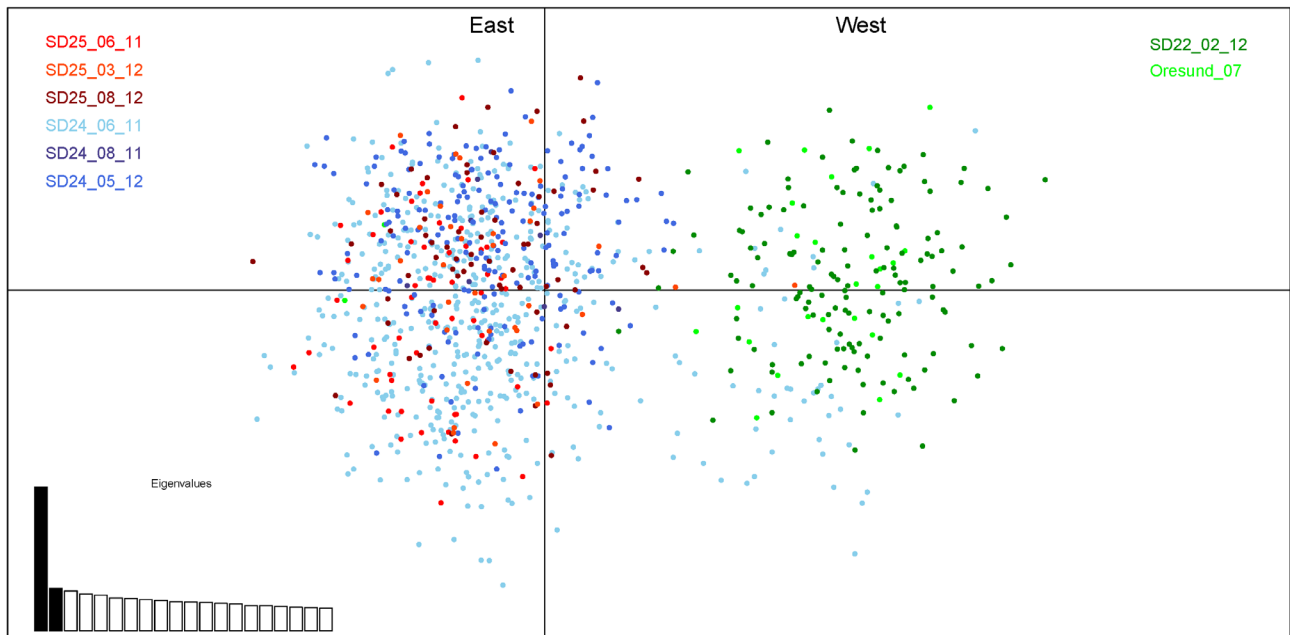


Figure 14. Principal component analyses of both baseline samples and samples originating from SD24. Sample codes are AREA_MONTH_YEAR. Note that the first principal component separates east and west and explains most of the variance in the data.

ASSIGNMENT OF SD24 INDIVIDUALS

Assignment of 756 individuals collected in SD24 identified an eastern origin for the majority of fish (67 individuals assigned to west while 689 fish assigned to east).

More detailed analyses revealed that fish assigning to the west tended to be smaller and immature compared to fish of eastern origin, of which many were in spawning condition (Figure 15). These data thus suggest that reproduction of the eastern component is taking place within SD24, at least in May and June where these samples were collected. Among the six western individuals in spawning condition, the genetic assignment score indicated that two were probably true western fish, while four may be hybrids (Table 2). The two fish assigning to the west with high certainty originated from harbour samples collected in May. Therefore, the position of the catch of these individuals within SD24 is unknown. Still, although these results should be interpreted cautiously given the low number of individuals, these data indicate that the western component may also be spawning in SD24. It should be noted that the samples collected in May represent the last part of the known spawning period of the western component (Bleil et al. 2009), and it is possible that earlier sampling may reveal a higher proportion of western fish in spawning condition.

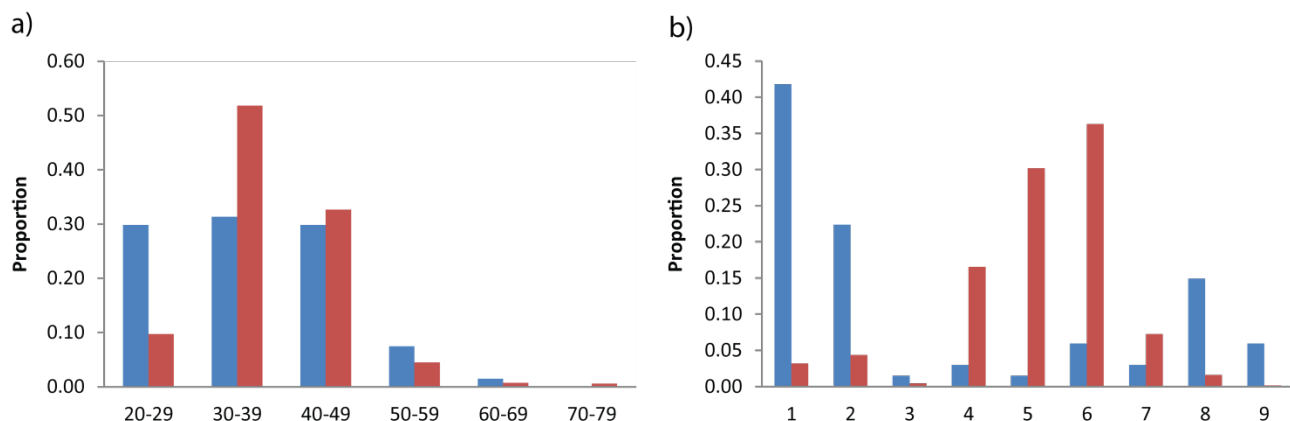


Figure 15. Distribution of eastern (red) and western (blue) individuals among size classes in a) and maturity stages in b). Maturity staging followed Tomkiewicz et al. (2002): 1: juvenile, 2: preparation, 3-4: ripening, 5: initiation of spawning, 6: main spawning period, 7: cessation of spawning, 8: spent, 9: regeneration. Stages 4 – 6 correspond to the “spawning” stage in the BITS manual (WKBIFS, 2013)

Table 4. Six fish in spawning condition assigning to the western component. An assignment score close to 100 indicates a “pure” western fish, while a score close to 0.5 may indicate a hybrid between the western and eastern component. Harbour samples were collected in May, while BALTICA samples were collected in June (see also Table1).

Fish ID	Sex	Length (cm)	Weight (kg)	Maturity Index	Assignment score
Harbour_0016	F	40	0.772	6	98.34
Harbour_0084	F	38	0.663	7	52.58
Harbour_0145	F	40	0.744	6	99.30
Harbour_0182	F	42	0.847	6	76.26
Harbour_0204	F	48	1.257	5	82.16
BALTICA_0620	M	34	0.38	6	63.3

The geographical distribution of assignments within SD24 for the BALTICA fish was highly heterogeneous (Figure 16). While very few western fish were found in the eastern parts of SD24, approximately half of the catch was of western origin in the western part of the Arkona Basin. These data clearly indicate a gradient of mixture between the two components. However, it should be noted that this should still be viewed as a snapshot from one month and one year, and therefore additional data would be highly valuable for assessing the spatial dynamics of mixing within SD24. Since each location in Figure 4 represents a single trawling event, the distribution also shows that both eastern and western fish may captured on the same hauls. These results therefore suggest that validated methods are needed for estimating the proportion of components in individual catches; particularly related to the geographical origin of the catch, which also seems to have an influence on the component specific harvesting rates.

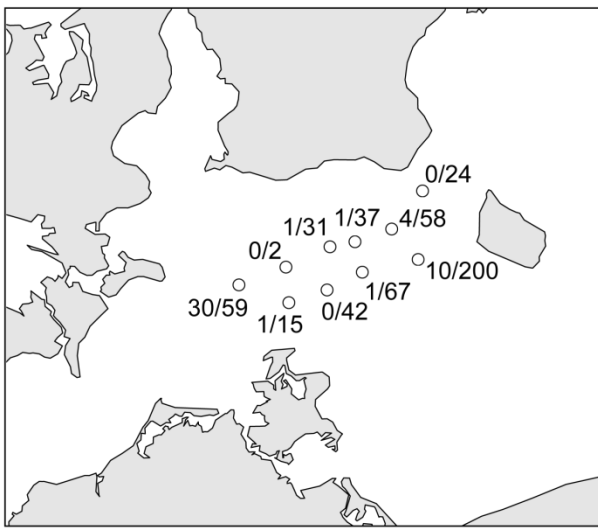


Figure 16. Geographic distribution of assignments to the western component. Numbers identify “number of fish assigning to western component”/”total number of fish analysed at location”.

4.3 OTOLITH SHAPE ANALYSES

Authors: Karin Hüsey and Henrik Mosegaard

INTRODUCTION AND METHODS

Background: Otolith shape is known to depend on a combination of genetic and environmental factors (Cardinale et al., 2004). Separation of populations in both time and space induces divergent otolith shape patterns (Messieh, 1972; Lombarte and Lleonart, 1993). As a consequence, the shape of otoliths has become of increasing importance in relation to stock management. The major focus of these studies has been on spatial and temporal discrimination of stocks (Bolles and Begg, 2000; Cardinale et al., 2004) as well as populations (Mérigot et al., 2007). The primary analytical tool in use is the Fourier Series Shape Analysis, based on which Bird et al. (1986) showed that otolith shape reflects differences between populations as well as differences between year classes of the same population in Alaskan and Northwest Atlantic herring. Also for herring in the North Sea, otolith shape analysis has proven a useful tool for separating catches into different spawning components. From 2009 and on otolith shape analysis has been used as a supplementary method to increase sample size for estimating stock proportions of North Sea autumn spawners and Western Baltic spring spawners in the mixing areas of Division IIIa and implemented in the routines for stocks assessment of these stocks.

Under the assumption that the different spawning stock components of cod in the Baltic Sea differ in otolith shape, this type of analysis therefore presents an inexpensive, fast method for estimating

stock proportions in a stock complex with mixed origin. To serve as baseline in this analysis, reference samples were collected from each ICES SD in the western and central Baltic Sea (SD's 22, 23, 24 and 25). Based on the assumption of natal homing for spawning (Svedäng et al., 2007), only spawning cod were collected from each major spawning area for these reference samples.

Methodology: Images of otoliths were digitised under a microscope equipped with a camera under standardised light and magnification settings. The otoliths were placed with the sulcus facing up and all placed in the same direction in order to eliminate any image-related bias and stored as JPG files. The contour of each otolith pair was captured using a MatLAB routine developed for otolith images. These contours consist of a sequence of x- and y-coordinates tracking the edge of each individual otolith. Elliptic Fourier Descriptors (EFD) were fit to the contours of each individual otolith using:

$$x_p = x_{cen} + \sum_{i=1}^{\infty} (A_i \cos \frac{2i\pi t_p}{T} + B_i \sin \frac{2i\pi t_p}{T})$$

$$y_p = y_{cen} + \sum_{i=1}^{\infty} (C_i \cos \frac{2i\pi t_p}{T} + D_i \sin \frac{2i\pi t_p}{T})$$

Where x_p is the x-coordinate of point p, y_p is the y-coordinate of point p, x_{cen} and y_{cen} are the coordinates of the centre point and T is the total number of data points in the contour. The procedure was set to resulted in 60 harmonics.

These EFDs were subsequently log transformed as $\ln(\text{EFD}_i+1)$ and standardised in relation to log fish length as the residual to the linear relationship $\ln(\text{EFD}_i+1)=a + b*\ln(L)$ and analysed in a quadratic Discriminant analysis. The reference samples consisting of spawning individuals captured in SD's 22, 23, 24 and 25, provided the information necessary to identify stock affiliation in this analysis, thus serving as the baseline for subsequent analyses of mixed stock samples. Stepwise Discriminant analysis was used to identify those descriptors with the highest discrimination power between stocks. The 21 most influential EFD's were selected stepwise from the entire data set. From these EFD's the stock-specific discriminant functions were developed to be applied to the mixed stock samples.

To evaluate the classification accuracy by the Discriminant analysis, jack-knife (leave one out) cross-validation was used.

RESULTS

DISCRIMINATION OF SPAWNING COMPONENTS

The Stepwise Discriminant analysis showed that the stock-specific differences in otolith contours are captured by a limited number of residual log transformed EFD's (Figure 17), in decreasing order of relevance: X3, A8, D5, X1, A9, D1, C2, X2, otolith-AREA, B2, X6, D2, C3, C8, D7, A19, A5, X5, B5, X4, D6, C9, and X11; where X_i is the combined information of all four EFDs at a specific harmonic i , $X = \sqrt{A^2+B^2+C^2+D^2}$. The numbers indicate which harmonic is involved, where harmonic 1 describes the ellipse encircling the contour, while harmonic 60 describes the smallest details superimposed on the general shape. Most significant EFD's are from low-number harmonics, indicating that the otolith shapes from the different stocks are different in the general shape characteristics (Figure 17).

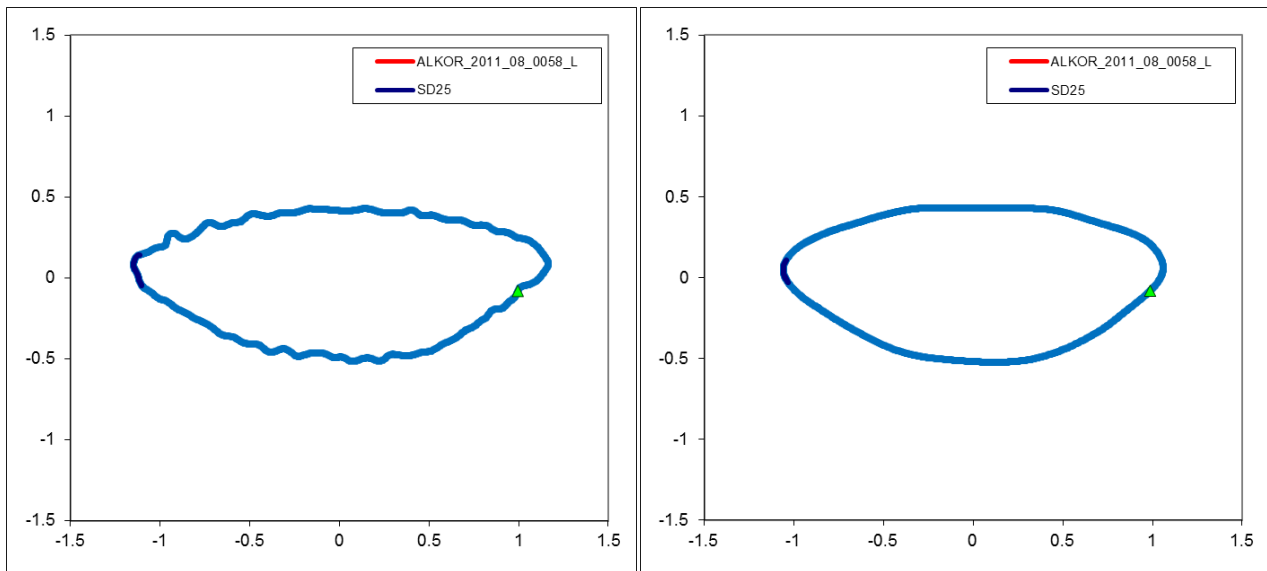


Figure 17 Left panel: individual otolith outline from a SD 25 cod, showing detailed contour with 60x4 EFDs. Right panel: Contour reconstructed from A1; Lower panel: The EFDs used in the discriminant analysis.

Individual cod from the baseline sample could be reassigned to one of the four SD types (Table 5). The overall cross validated assignment success was 64% for spawning individuals assigned to their own spawning group. However SD23 had a poor power of only 10% correct assignment due to the low number of individuals. It is also evident that there is a relatively high mutual reassignment error between SD24 and SD25, whereas virtually no incorrect assignment into SD22.

Table 5. Summary of the jack-knifed cross validation, % and number of otoliths in brackets

Reassignment success	number of otoliths into SD			
from SD	22	23	24	25
22	67% (225)	3% (9)	14% (47)	16% (53)
23	43% (26)	10% (6)	17% (10)	30% (18)
24	3% (45)	0% (5)	62% (901)	35% (505)
25	3% (50)	1% (8)	29% (450)	68% (1066)

The scatterplot of the two first canonical discriminant functions is shown in (Figure 18). This figure shows that cod from SD 22 (black dots) are to a large extent separated from SD 24 (red circles) and SD 25 (blue circles), but group with cod from SD 23 (orange dots). The SD 24 and 25 types show some separation, but with an extensive overlap. This analysis thus shows that the true “Western” cod stock has an otolith shape that significantly differs from the true “Eastern” otolith type. The analysis has also shown that the difference in otolith shape between fish caught in SD 24 and 25 may differ, but that the differences are very small. Considering the results from the genetic analysis, this limited separation between SD 24 and 25 cod shows that most of the cod spawning within SD 24 are in fact “Eastern” cod. However, the overlap is not complete, which suggests that at least a proportion of the “Eastern” immigrants have stayed for some time in SD 24 – which, owing to the different environmental conditions in that area compared to the Eastern Baltic, has resulted in a slightly different otolith shape.

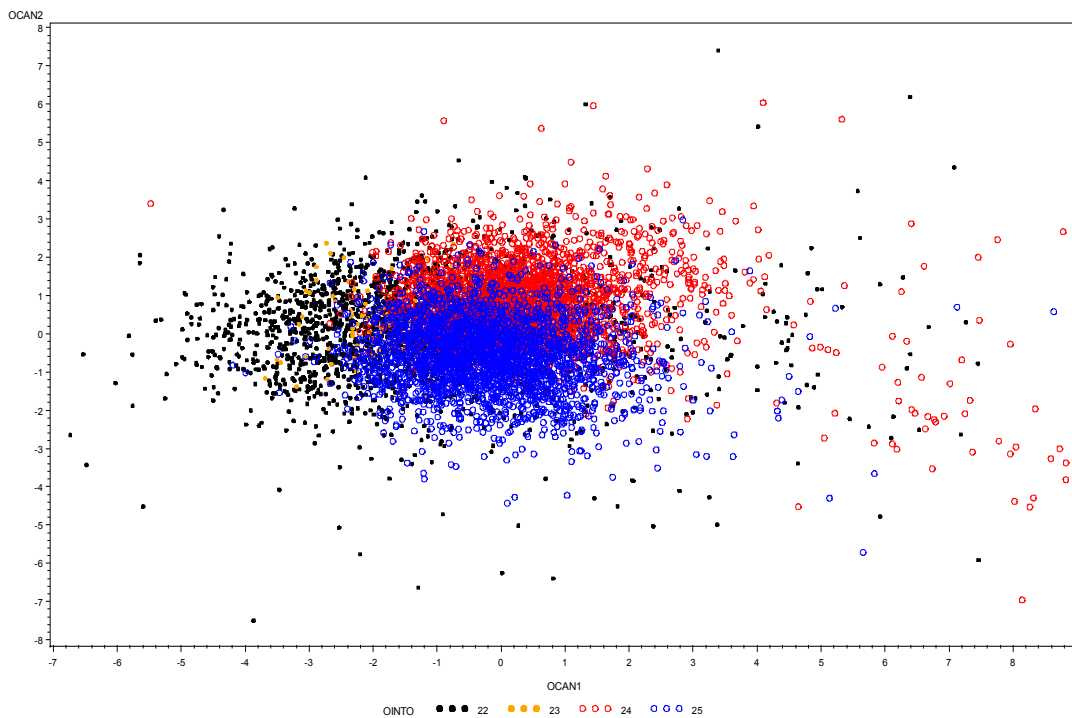


Figure 18. Scatterplot of the first two canonical discriminant functions based on EFD's using all spawning individuals caught in the different SD's. Symbols represent: Black = SD 22, orange = SD 23, red = SD 24 and blue = SD 25.

ANALYSIS OF MIXED STOCK SAMPLES:

In order to estimate stock mixing rates, archived otoliths from SD 24, the presumed mixing area, were digitised and subjected to the same MatLAB routines for capturing otolith contours. The stock-specific identification formulas obtained from the baseline analysis, were then applied to the mixed stock otolith contours and each otolith was assigned with probability of belonging to the four different SD's (22, 23, 24, and 25). From these probabilities the one with the highest score was selected as the individual's stock affiliation. The analyses carried out in WP3 are based on these stock assignments.

4.4 COMPARISON OF GENOTYPING AND OTOLITH SHAPE ASSIGNMENT

During the “Baltica” cruise in SD 24 in June 2011, samples from non-spawning individuals were collected with the objective to establish a test-sample for comparing stock assignment methods. For each individual fish the assignments obtained from genotyping and otolith shape analysis were compared. A total of 121 fish were analyzed by both methods.

The result of this comparison is summarized in Table 6. From the reassignment analysis of the otolith base line of spawning cod it should be expected that most cod would be assigned to their native spawning population, approximately two thirds. Analysis of two different stocks each with two different growth conditions shows that environment besides genetics has a high influence on otolith shape development (Cardinale et al. 2004). The results from the Baltica survey on non-spawning fish however indicate that cod move between SD's. For the cod with an “Eastern” genotype it could argued that some have immigrated recently, whereas others have been in the Western environment for some time and thus obtained an otolith shape that differs from the original “Eastern” shape producing a 48% SD 24 type cod instead of the expected 29% from random assignment noise. For fish with a “Western” genotype a similar picture emerges. A small proportion (9%) appears have immigrated from SD 22 recently, while 29% of the fish have attained a SD 24 otolith type. These fish thus seem to have spent a longer period of their lives outside SD 22. But the high percentage (62% in relation to an expected 16%) of “Western” fish that were assigned to SD 25 by otolith shape analysis needs a more complex interpretation were the influence of environmental processes of active migration and passive drift of early life stages across SD's and the interaction between genotype and environment on the actual shape development needs a better understanding – and where the interacting processes may not be fully captured by the applied methods (Hüssy, 2011, Hüssy et al., 2012, Hinrichsen et al., 2012). As these “Western” individuals assigned to SD 25 to a large extent consisted of small fish, this result may also point to the problems with a somewhat unbalanced baseline for the otolith shape analysis, consisting of mostly large adult individuals especially in SD 22 which may not be ideal for assigning immature and smaller individuals in mixed samples.

Table 6. Summary of assignment method comparison on non-spawning fish captured in SD 24. Genotype assignment is into “Eastern” or “Western”, while otolith assignment is into SD. The numbers represent percentages of the fish of a given genotype assigned to different SD’s by otolith assignment. Numbers in brackets are the average size of cod within the different assignment groups.

		Otolith assignment								
		SD 22			SD 24			SD 25		
		%	n	cm	%	n	cm	%	n	cm
Genotype assignment	Eastern (SD 25)				48	31	33	52	34	32
	Western (SD 22)	9	5	50	29	16	36	62	35	32

4.5 CONCLUSIONS

- The biological data on mean length, weight and condition indicate that the proportion of cod of eastern origin in SD 24 has increased in recent years (since 2007). Since 2007, the mean weight and length of older cod in SD 24 has become similar to that in SD 25, while in the earlier time period the weight and length was higher in SD 24 than in SD 25. Despite the drastic reduction in mean weight of older cod in SD 24, a similar decline in condition of cod in SD 24 as observed in SD 25 is not apparent. In SD 25, the drop in mean weight since 2007 is considered to be due to food limitation, which should not be the case in SD 24, supported by the better condition of cod in SD 24. The drastic decline in mean weight and length in SD 24 since 2007 is therefore likely due to an increased proportion of generally smaller cod of eastern origin found in the area.
- Data on maturity stages in the 1st quarter shows a high proportion of cod in SD 24 at a stage to skip spawning; however this proportion has been stable since the 1990s.
- Genetic analysis revealed a clear separation between “Eastern” and “Western” baseline samples, and a resultant high and temporally stable statistical power for assigning individuals back to their stock of origin. Thus, this project has identified genetic assignment as a highly reliable tool for estimating catch proportions in mixed fisheries.
- The highest proportion of “Eastern” genotype cod in SD 24 occurs among ripe and spawning individuals in the size range 30-39 cm.
- Genetic assignment of fish from the same trawling event to both western and eastern components indicates that fisheries are targeting both components simultaneously
- An east-west gradient from high to lower proportion of eastern fish in the catches calls for the incorporation of spatial information in cod management within SD24.
- Otolith shape analysis can with reasonable accuracy discriminate between “Eastern” and “Western” Baltic cod, assigning 2/3 individuals back to the expected baseline sample. These

results suggest that population-specific signals are partly captured by otolith shape, but that immigrants may be difficult to assign with high accuracy after prolonged occupation of a specific area due to the fact that otolith shape is influenced by area-specific environmental conditions.

- Cod spawning in SD 24 are primarily “Eastern” genotype, with an otolith shape more similar to the true “Eastern” than the “Western” cod. Both analytical approaches thus document that a considerable immigration of “Eastern” cod into SD 24 has occurred.
- The comparison of genotype with stock assignment based on otolith shape indicates that fish may either migrate in and out of SD 24 or immigrate and stay. But the present study does not provide conclusive results, most likely due to substantial spatial and temporal environmental variation influencing individual otolith shape and uncertainties over when SD specific signatures are imprinted in the otoliths. Therefore, further research into the migration dynamics of *individual fish* in the area is needed.
- SUMMARY: All analyses carried out in this WP’s show that a considerable immigration of “Eastern” cod into SD 24 has occurred, and that these individuals also spawn in SD 24. Combining results from genotyping (for natal stock affiliation) and otolith shape analysis (identification of environment inhabited) was explored as a tool for quantifying individual fish migration dynamics. However, results were difficult to interpret and further development is needed for the tool to be operational (i.e. Data Storage Tags and otolith microchemistry, see “Future recommendations”).

Milestones:

M3. Genetic stock identification (September 2012)

M4. Otolith-based stock identification (September 2012)

Status: *Accomplished*

5. WP3: QUANTITATIVE EVALUATION OF STOCK COMPOSITION AND TRENDS IN THE WESTERN BALTIC SEA

Authors: Karin Hüssy and Margit Eero

5.1 ANALYSES OF BIOLOGICAL STOCK DATA

To investigate cod dynamics in SD 22 and SD 24, stock assessments were conducted separately for the two areas using stock assessment model SAM, that is applied to assess the development and status of the western Baltic cod in ICES. Cod dynamics in SD 25 was derived from an area-disaggregated multispecies model SMS for the Baltic Sea.

The results of separate stock assessments for SD 22 and 24 show a substantial increase in the SSB of cod in SD 24 since 2005 to the highest level observed since the mid-1980s. In contrast, the biomass of cod in SD 22 has declined since 2000s (Figure 19). The difference in stock dynamics between SD 22 and 24 is even more pronounced when looking at stock numbers instead of biomass. This is due to a drastic reduction in mean weight in SD 24 in recent years, implying that the increase in biomass is not as large as the increase in abundance of older cod. The stock numbers of older cod (4+) in SD 24 are currently at the highest level observed since mid 1980s, whereas recruitment (ages 1) varies around a constant mean during the entire time series since the mid 1980s (Figure 22).

Comparison of stock numbers across SDs reveals similar trends over time in SD 25 and SD 24 for older (4+) cod, with higher abundances in mid 1980s, mid 1990s and since 2007. The cod abundance in SD 22 has been in line with these trends until recently (2007), when the abundance in SDs 24 and 25 sharply increased but in contrast declined in SD 22 (Figure 21).

Stock- recruitment analyses of results from separate assessments for SD 22 and 24 show no relationship between recruitment and SSB in SD 24 (Figure 22). In SD 22, some tendency towards higher recruitment at higher SS is recorded. Recruitment in the entire western Baltic Sea (SD 22-24) has been low in recent years, despite the large SSB in SD 24. Thus, the recruitment in SD 22-24 seems to follow the trends in SSB in SD 22 (Figure 23).

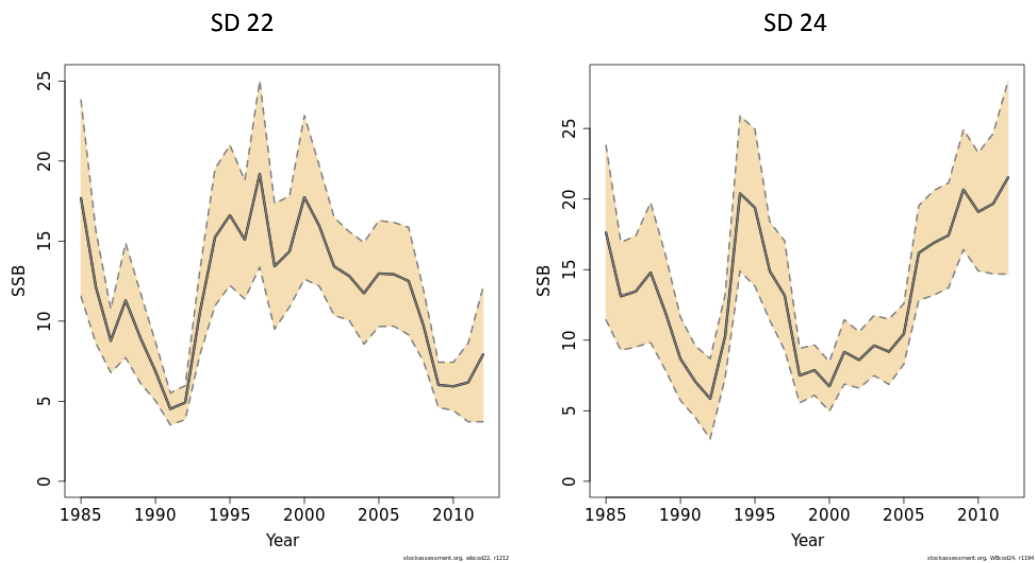


Figure 19. Spawning stock biomass of cod in SD 22 and SD 24.

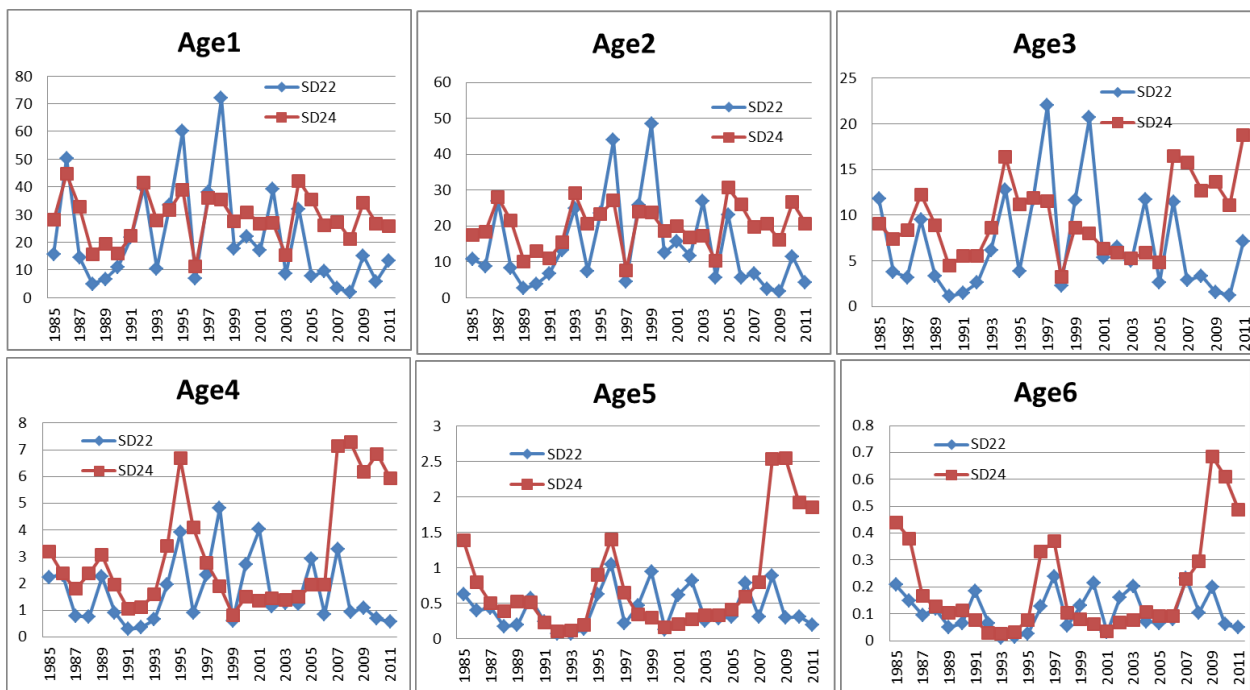


Figure 20. Stock number at age in SD 22 and SD 24.

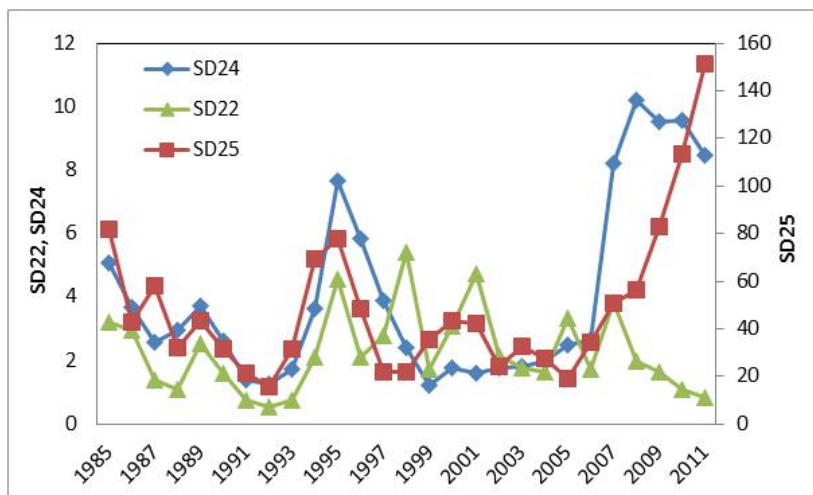


Figure 21. Abundance of older (4+) cod in SD 22, 24 and 25.

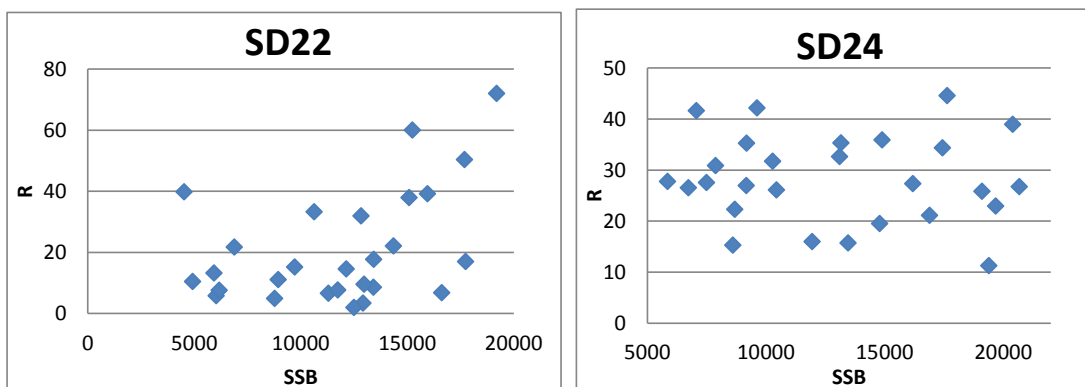


Figure 22. Stock-recruitment relationship from separate assessments for SD 22 and SD 24.

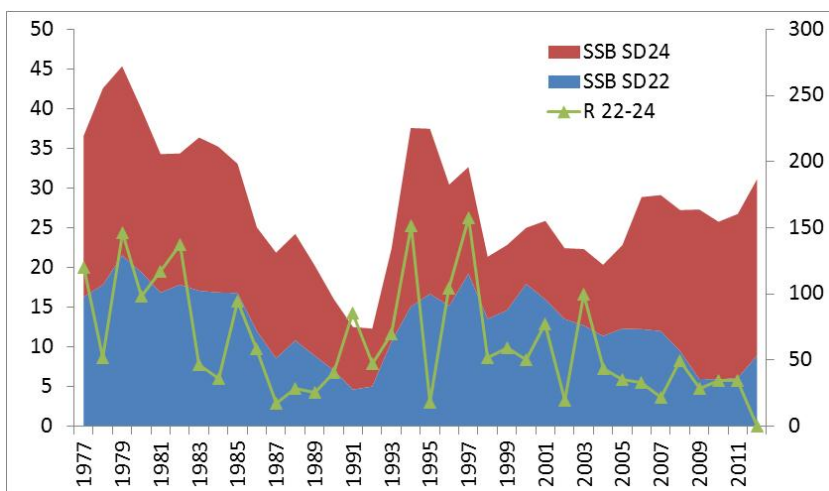


Figure 23. Spawning stock biomass of cod in SD 22 and 24, and recruitment in the entire western Baltic Sea (SD 22-24).

5.2 STOCK MIXING ESTIMATED FROM OTOLITH SHAPE ANALYSIS

In order to estimate stock mixing rates, archived otoliths from SD 24, the presumed mixing area, were digitised and subjected to the same MatLAB and discriminant analysis routines. The samples used consisted primarily of harbour samples representing the catches by the fishery in SD 24, with some discard samples. From the assignments of each individual fish, the proportional compositions of the samples were calculated as:

$$P_{\text{Eastern}} = n_{\text{Eastern}} / n_{\text{total}}$$

where P_{Eastern} is the proportion of eastern Baltic cod in SD 24, n_{Eastern} is the number of otoliths assigned to the Eastern Baltic cod stock and n_{total} is the total number of otoliths analyzed. For this analysis reference samples were collected from each ICES SD in the western and central Baltic Sea (SD's 22, 23, 24 and 25). The following results relate the % occurrence of the SD-specific otolith types in SD 24. A 30% for SD 22 thus means that of the analysed cod in SD 24 30% were of the type resembling individuals spawning in SD 22.

Proportions were calculated in order to analyze the effect of season, year and age on the stock mixing in SD 24.

The rationale for analyzing the available sample based on SD-specific otolith types and not merely an “Eastern” and “Western” type was to prevent forcing the results into ecologically inappropriate constraints. Otoliths continue growing throughout the life of the fish. Therefore, fish that are originally from the Eastern stock but have moved into SD 24 and have stayed there for some time (and spawn there) will over time develop otoliths that are influenced by the environmental conditions in SD 24 and thus become more similar to the “Western” type (Cardinale et al., 2004). With the “SD-specific otolith type” setup, we allow for such fish to be assigned to their own group.

EFFECT OF SEASON

In order to evaluate whether the mixing was subject to seasonal migration patterns, stock compositions was examined in relation to quarter for the years 2000, 2008 and 2010. No specific pattern was evident for any of the years (examples shown for the years 2008 and 2010; Figure 24). This shows that there is no apparent seasonal migration in and out of SD 24 associated with the spawning cycle of cod. Consequently, samples from all quarters were pooled in the subsequent analyses.

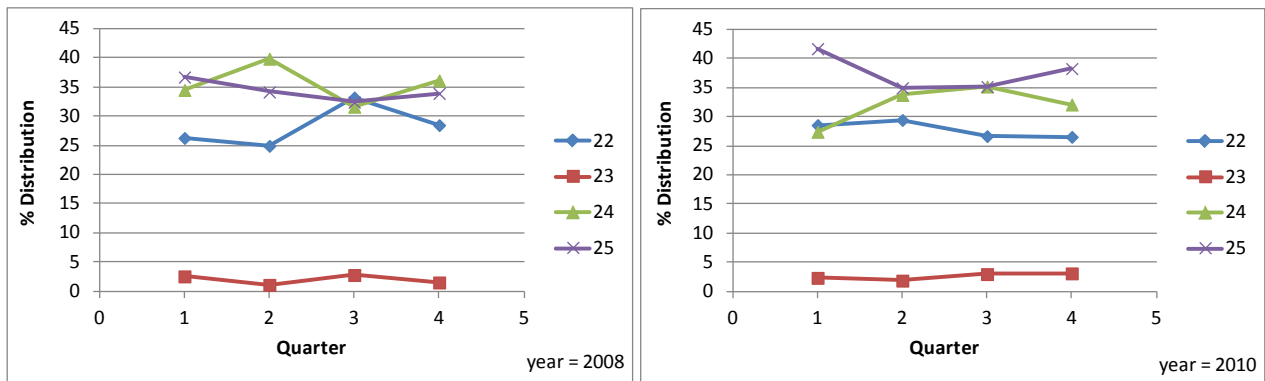


Figure 24. Stock mixing in SD 24 over the 4 quarters within specific years, with % contribution of the otolith types specific for SD's 22, 23, 24 and 25. Left panel: year 2008, right panel: year 2010, where the different colors represent the different SD's according to the legend.

EFFECT OF AGE

Across all years examined with adequate numbers in a given age class, the pattern was similar: The proportion of SD 23 cod in SD 24 was completely constant with age. The proportion of “Eastern” cod (SD 25) was relatively constant across age classes up to the year 2005. In the second half of the 2000's, the proportion of “Eastern” cod showed a strong increasing trend with age. This increase in “Eastern” cod is balanced by a decreasing trend in SD 24 type, while the SD 22 type is relatively stable across age classes (Figure 25). Even though there is considerable variability associated with the estimates, the trends are the same in completely different years and can therefore be considered as reliable. These results indicate that in recent years an immigration of “Eastern” cod into SD 24 has taken place, and that this immigration has consisted mainly of older individuals. As the stock mixing is based on proportions, the decrease in SD 24 type is a direct consequence of this increase in “Eastern” cod.

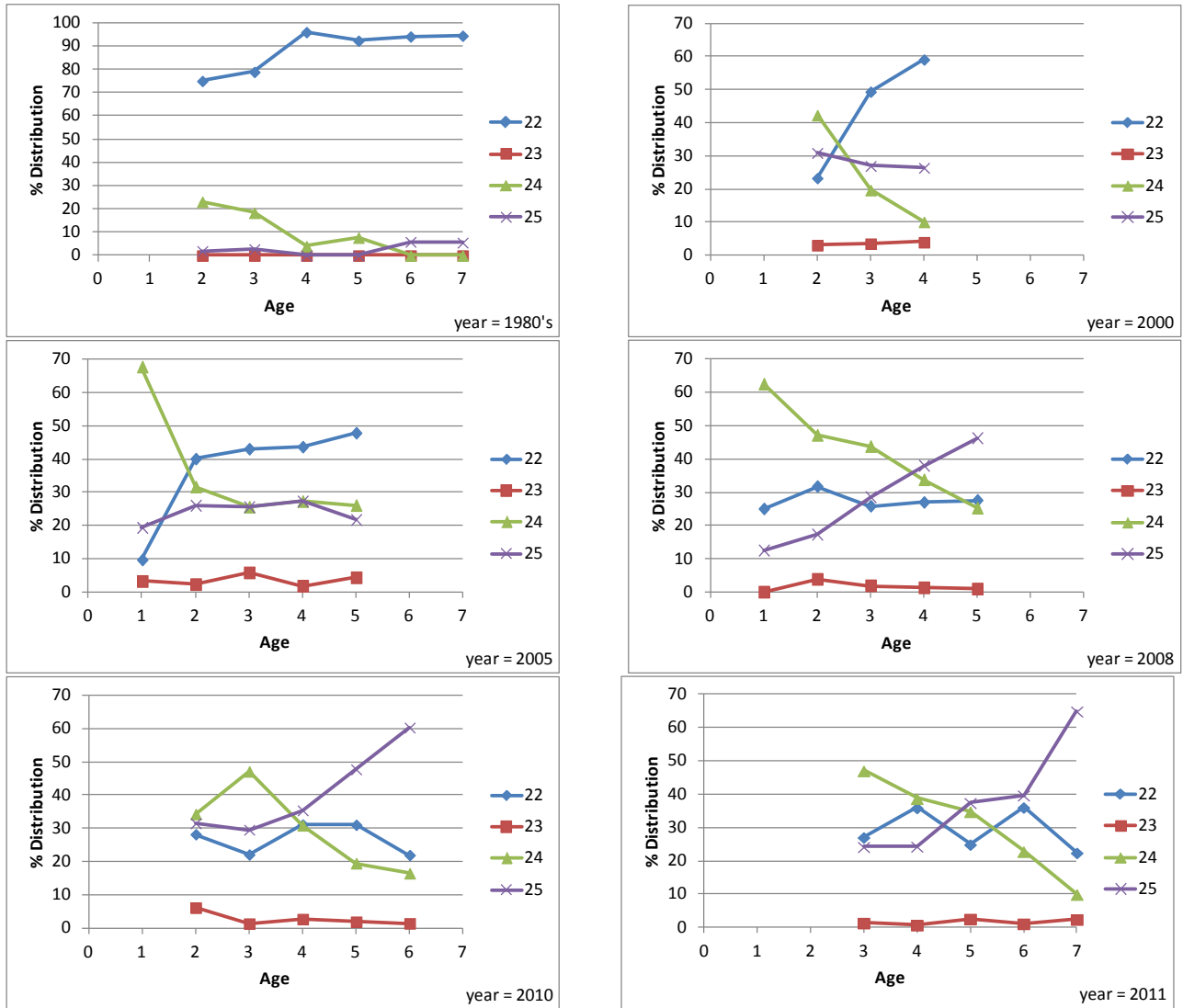


Figure 25. Stock mixing in SD 24 over the 6 years analyzed (from top left to bottom right: 1980's, 2000, 2005, 2008, 2010, 2011), with % contribution of the otolith types specific for SD's 22, 23, 24 and 25 (The colors represent the different SD's specified in the legend and the years are indicated in the bottom right corner of each graph).

STOCK MIXING OVER THE LAST 30 YEARS

In order to evaluate the historic trend in stock mixing, samples from the 1980's and from 2000 onward were analysed. This analysis shows a clear picture: In the 1980's cod in SD 24 primarily consisted of SD 22 and SD 24 types, together making up > 95% of the stock. By the early 2000's the "Eastern" component (SD 25) had increased to ca. 25%, and in the second half of the 2000's increased steadily to almost 40%. Over the entire period examined, SD 23 type remained at a constant, low level of 2-3% (Figure 26). Otoliths from the early 1980's were extremely fragile and many were broken. This may hamper the correct assignment to stock by shape analysis, as there is no image-analysis based method for correcting for this problem. But as the assignment to SD 23 remained constant across all years examined, we consider the 1980's results as fairly accurate.

It is well known that the shape of otoliths changes in accordance with the environmental conditions they live in (Cardinale et al., 2004), but the speed with which this happens is not known. The present results document a considerable immigration of "Eastern" cod into SD 24 - the SD 25 type which contributes with 35-40%. The results also show that approximately 30% of cod in SD 24 are "Western" (SD 22 type) cod. But the results do not allow any conclusion with respect to the SD 24 type. These fish could originally have immigrated from either SD 22 or 25 and have settled there. Alternatively, they may form their own separate stock component. However, based on the results from the genotype mapping, the latter explanation does not seem likely.

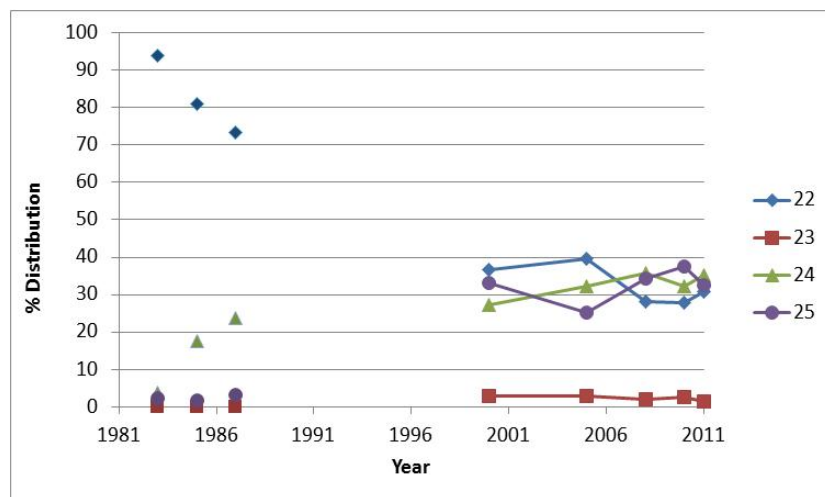


Figure 26. Stock mixing in SD 24 over the last 30 years, with % contribution of the otolith types specific for SD's 22, 23, 24 and 25. The colors represent the different SD's specified in the legend. As the reliability of the 1980's samples is hampered by broken otoliths, the connecting lines are not extended to these.

Due to problems with matching samples and data from the 1990's there is so far no information available for that decade. This problem has been solved recently and samples from are being processed, but the results will not be available before the end of this project.

5.3 CONCLUSIONS

- The dynamics of adult cod in SD 24 has been similar to that in SD 25 during the entire time series since the 1980s, which indicates generally close association between the stock components found in SD 24 and SD 25. The dynamics in SD 22 has been in line with the dynamics in SD 24-25 until recently (2007). Thus, the different stock components within the western Baltic management area have not been an issue until recently, when cod abundance in SD 22 started to substantially deviate from that in SD 24.).
- The recruitment shows no association with the size of the spawning stock in SD 24. The trends in cod recruitment in the western Baltic area (SD 22-24) follow the dynamics of SSB in SD 22.
- Otolith shape-based stock mixing analyses found no seasonal migration of “Eastern” cod in and out of SD 24
- Since the 1980’s where cod in SD 24 consisted primarily of “Western” type, the proportion of “Eastern” cod has increased. With the available temporal coverage, the latest increase has been shown to occur after 2005.
- Immigration of “Eastern” cod into SD 24 consisted primarily of adult fish, with increasing proportions with fish age throughout all years since 2005
- SUMMARY: Stock assessment data and stock mixing proportions by otolith shape analysis complement each other, showing that after 2005 an immigration of “Eastern” cod into SD 24 has occurred and that this immigration particularly is attributable to the immigration of older individuals. Thus, although statistical power for individual assignment based on otolith shape may not be high (see WP2), otolith shape analyses do seem to have captured the recent and dramatic inflow of larger eastern fish, as suggested by biological data.

Milestones:

M5 Quantitative evaluation of stock mixing of the cod stocks in the western Baltic Sea, including effects on stock assessment (October 2012)

Status: *Accomplished*

6. WP4: ANALYSIS OF MANAGEMENT MODELS

Authors: Francois Bastardie and Rasmus Nielsen

6.1 INTRODUCTION

This study evaluated the effect of the mixing between eastern and western Baltic cod (*Gadus morhua*) on the dynamics of the two cod stocks, as well as the implication of migration between sub-areas (i.e. from ICES subdivisions 22 and 25 to 24). The evaluation accounts for the implementation of the long-term cod management plan which set a target level for the exploitation of the two stocks (an F-target corresponding to the single-stock FMSY) to be reached gradually after applying a Harvest Control Rule (HCR) each year (EC, 2007). For the Baltic cod stocks the plan set a TAC that correspond to a reduction of F by 10% each year until reaching the F target (0.6 for the western stock).

There are some indices for a recent increase in the mixing between the eastern and western Baltic cod populations (WP3), a recovery of the eastern cod stock with larger abundance (WP2) and, finally, a shift of the fisheries toward allocating more effort to the eastern part of the western Baltic area, which makes it relevant to investigate their potential effects on the capacity of the western stock to reach the management targets or to evaluate whether these targets need to be redefined accordingly.

The purpose of this study is to evaluate the expected outcome and performance of the long term management plan in achieving the targets in a (increased) stock mixing and changed fisheries effort allocation situation. By informing a Management Strategy Evaluation (MSE) model, stochastic simulations are carried out under different scenarios of mixing and migration and catch proportion per sub-area. The performance of the management plan to reach the target in the harvest control rule (HCR) according to stock sustainability (Maximum Sustainable Yield, MSY, approach), deliver sustainable yields, and robustness to alternative management scenarios are examined.

6.2 METHODS

The evaluation used FLR (Fisheries Library in R, Kell *et al.* 2007) which is a management strategy evaluation framework for running stochastic simulations of stock and fisheries dynamics given different input scenarios. A specific FLR model (Baltic FLR) has been developed for the Baltic Sea cod stocks and fisheries (Bastardie *et al.*, 2010), and this model has been further modified and informed for the present analyses. The MSE tool is used for scenario evaluation of the relative performance of different options for management and different options on stock and fisheries dynamics (and their status), and potentially on decisions for reaching management objectives in relation to these different scenarios. The MSE stochastic simulation framework comprises two

elements: the operating model OM, and the management procedure MP. The OM represent standard plausible alternative population states and dynamics over time such as different levels of recruitment, different relationships between spawning stock and the recruitment (SBB-R), different catch levels and fishing mortalities, different catch proportions between areas, and other stock (and fisheries) dynamics over time. The MP or management procedure is the combination of the available simulated data, the stock assessment ('perceived' stock status) and the management model or Harvest Control Rule (HCR) deciding e.g. on the next total allowed catch (TAC). An important aspect of MSE is the feedback of management decisions from the HCR into the OM so their impact is reflected in the simulated stock dynamics.

The management strategy evaluation model developed for the Western Baltic cod stock here is a stock-based evaluation (Bastardie *et al.* 2010), corresponding to the minimum required according to the ICES SGMAS (ICES, 2008). In the current application the model is spatial explicit comprising two separated areas for SD 22 and SD 24 allowing for movement of cod between the two areas and into the two areas from outside (e.g. from SD25). As the influence of migration from east (SD 25-32) to west (SD 24) is expected to be low on the eastern Baltic cod stock, mainly distributed in SD 25-32 this is not explicitly modelled in the present scenario analyses. Instead, a proportion of eastern cod is annually added to SD 24, to test the effect of immigration from the east on the western stock.

The age-structured model (ages 1 to 7+) is simulating the yearly interlinked dynamics of the two western Baltic cod sub-stock components (SD 22 and SD 24 stocks). The simulations begin from 2006 and onward up to a 20 years' time horizon. The management procedure defined by the long-term cod management plan is applied from 2011 and onwards and set the first TAC for 2012. Before this period (e.g. 2006-2011), the historical TACs for the western stock are used for the period 2006-2011.

The initial OM population per sub-stock is the assessed median stock numbers N in 2005 provided by the last 2012 ICES assessment (ICES, 2012) using the SAM assessment model (State-space stochastic Assessment Model, Nielsen and Berg, 2009) on the separated sub-populations in SD 22 and SD 24. Biological parameters (weight-at-age, maturity-at-age and natural mortality-at-age) are the historical ones (i.e. used in the ICES assessment) for the period 2006-2011, and averages over the period 2006-2011 is used for the projection period. The MP management procedure is applied on the overall western stock after summing the actual stock numbers (SD 22 + SD 24). Within the MP, the assessment of the population at $y-1$ (the 'perceived' stock) is mimicked each year from the same variance/covariance matrix used by the SAM model. Like in the normal ICES procedure, a short-term forecast (STF) of the population status is then made to forecast the stock numbers two years ahead (i.e. $y+1$) by applying the intended F from the HCR (i.e. $F_y = F_{y-1} \cdot 0.9$) in the intermediate year y and in the forecast year $y+1$ (i.e. $F_{y+1} = F_y \cdot 0.9$). A geometric mean over 1996-2005 (20 years) for fixed recruitment at age 1 is used. The TAC at $y+1$ is then deduced from the forecasted population and the intended F . By default, and in agreement with the long-term cod management plan, the overall TAC is furthermore constrained to remain within a $\pm 15\%$ interval from the previous year TAC.

Table 7: 2012 SAM stock assessment estimates of stock numbers for the year 2005.

	median	low	high	mean
N0	60596.96	43000.20	85394.76	61494.90
N1	38368.80	27388.54	53751.13	38917.77
N2	33057.38	23225.36	47051.59	33576.31
N3	4799.66	3230.59	7130.81	4894.61
N4	1844.75	1176.71	2892.05	1891.96
N5	355.28	207.49	608.32	368.36
N6	76.36	42.00	138.82	79.84
N7	34.39	16.68	70.87	36.71
F1	0.06	0.03	0.12	0.06
F2	0.45	0.26	0.79	0.47
F3	0.76	0.47	1.21	0.78
F4	1.04	0.67	1.62	1.07
F5+	1.22	0.81	1.82	1.24

Table 8: 2005 Variance/covariance SAM matrix on stock numbers from the 2012 assessment

	logN0	logN1	logN2	logN3	logN4	logN5	logN6	logN7	logF1	logF2	logF3	logF4	logF5+
logN0	0.0294	0.0041	0.0038	0.0036	0.0014	0.0009	-0.0004	-0.0001	-0.0035	0.0014	0.0024	0.0009	0.0001
logN1	0.0041	0.0284	0.0060	0.0011	0.0003	-0.0004	-0.0014	-0.0008	-0.0029	0.0051	0.0023	0.0008	-0.0001
logN2	0.0038	0.0060	0.0312	0.0005	0.0000	-0.0007	-0.0014	-0.0010	-0.0091	0.0139	0.0040	0.0009	-0.0002
logN3	0.0036	0.0011	0.0005	0.0392	0.0042	0.0025	0.0026	0.0013	-0.0040	-0.0165	0.0181	0.0029	0.0007
logN4	0.0014	0.0003	0.0000	0.0042	0.0505	0.0052	0.0037	0.0014	-0.0006	-0.0067	-0.0125	0.0198	0.0028
logN5	0.0009	-0.0004	-0.0007	0.0025	0.0052	0.0723	0.0093	-0.0054	0.0004	-0.0047	-0.0026	-0.0115	0.0151
logN6	-0.0004	-0.0014	-0.0014	0.0026	0.0037	0.0093	0.0893	0.0421	0.0012	-0.0031	-0.0026	-0.0058	-0.0055
logN7	-0.0001	-0.0008	-0.0010	0.0013	0.0014	-0.0054	0.0421	0.1308	0.0007	-0.0024	-0.0015	0.0012	-0.0175
logF1	-0.0035	-0.0029	-0.0091	-0.0040	-0.0006	0.0004	0.0012	0.0007	0.1232	-0.0063	-0.0032	-0.0010	-0.0000
logF2	0.0014	0.0051	0.0139	-0.0165	-0.0067	-0.0047	-0.0031	-0.0024	-0.0063	0.0752	-0.0105	-0.0025	-0.0015
logF3	0.0024	0.0023	0.0040	0.0181	-0.0125	-0.0026	-0.0026	-0.0015	-0.0032	-0.0105	0.0548	-0.0074	-0.0021
logF4	0.0009	0.0008	0.0009	0.0029	0.0198	-0.0115	-0.0058	0.0012	-0.0010	-0.0025	-0.0074	0.0494	-0.0058
logF5+	0.0001	-0.0001	-0.0002	0.0007	0.0028	0.0151	-0.0055	-0.0175	-0.0000	-0.0015	-0.0021	-0.0058	0.0402

Table 9: Overall TAC in kg for the western Baltic cod stock (SD 22 + SD 24) + assuming 4% of discards.

	2006	2007	2008	2009	2010	2011
Official western cod TAC (+4% discards)	21670	24960	20800	15912	14664	16952

Table 10: Proportion of the western cod catches taken in the SD 22 area estimated from the official ICES landings.

	2006	2007	2008	2009	2010	2011
Catch proportion in SD 22	0.48	0.37	0.32	0.23	0.30	0.36

For each year (y), the TAC for the full western cod is split into two parts, one for the SD 22 and one for the SD24 sub-stock according to the proportion of landings expected to be realized in each sub-division. By default, these proportions are based on the observed historical distribution of landings by sub-division for the period 2006-2011, and the proportion in 2011 are used for the following years. The resulting sub-division specific TACs at y are then converted into fishing mortalities (Fs) at age for the year, y, according to the catch equation (Baranov, 1948) to be applied for the OM populations. The catch equation is solved numerically to deduce the Fs at y from the last Fs at y-1 and a multiplier, assuming constant natural mortality. Accordingly, the Fs at y are the fishing mortalities by age that will realize the TACs given the actual stock status. An overall F at the scale of the entire western Baltic area (SD22+SD24) is finally deduced back from the total removals and the stock status by year.

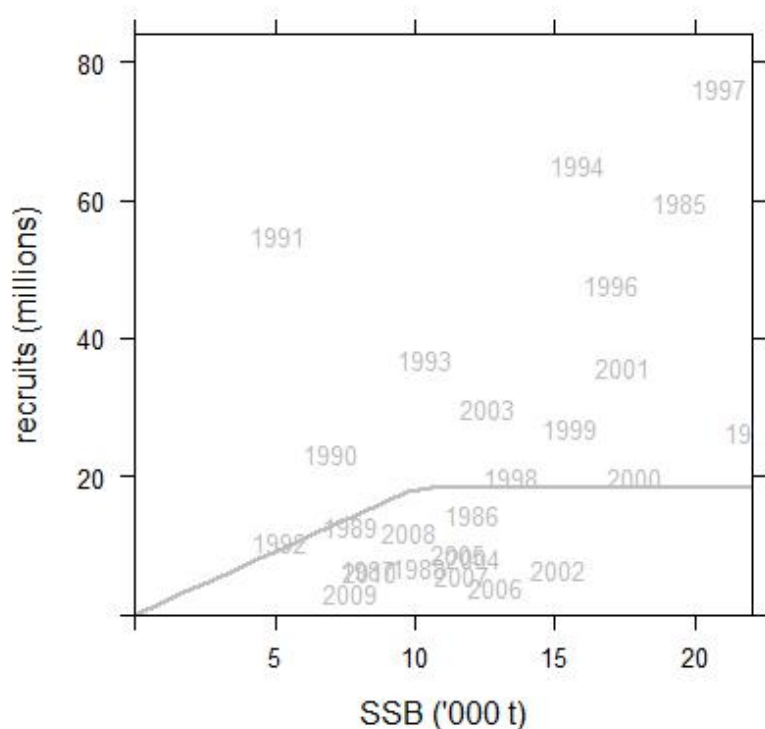


Figure 27. Segmented regression for the SSB-R relationship in the SD 22 area from the period 1985-2011 with inflexion point at SSB=10kt.

The aggregation for spawning and recruitment (at age 1) is assumed to occur in the SD 22, i.e. only originating from the population present in the SD 22 (i.e. no spawning event in SD24 is included). The level of spawning in SD24 (Arkona Basin) is unknown, and not considered to be significant (Hüssy, 2011). Consequently, the SSB-R relationship from SD 22 (Figure 27) is used for the full stock. The SSB-R relationship is fit from a segmented regression applied on the 1985-2011 data with a threshold (inflection point) at SSB=10 kt. Consequently, the age 1 cod in SD 24 is then assumed to only originate from SD 22 spawning and immigrants.

The age-specific net migrations between areas are deduced from otolith shape analyses of stock-affiliation for representative samples of individuals from SD24 (see WP3, Figure 25). The otolith shape based assignment of the cod sampled in SD 24 enables assessment of origin of the cod according to area (sub-division SD). Consequently, there is performed an area classification of each individual sampled cod in SD 24 to be either true SD 24 cod, or SD 22 cod, or eastern cod.

The samplings and analyses cover the years 2005 and 2011, and the net migration is calculated for these years. Area specific frequencies of otolith types sampled in SD24 are shown in Table 13.

Absolute numbers at age of incomers to SD 24 from the East added to the SD 24 population each year (*fish_East_to_SD24_in_2005*), have been deduced from the 2005 baseline year relative distribution (percentages in Table 11) as given below.

The table gives the following area percentages by age:

$$\text{prop_fish_East_in_SD24_in_2005_at_age} = \{0, 0.19, 0.26, 0.26, 0.27, 0.22, 0, 0\}$$

The absolute numbers of eastern cod migrated to SD24 (incomers to SD24 from the east) by age is calculated from:

$$\text{fish_East_to_SD24_in2005} = \text{prop_fish_East_in_SD24_in_2005_at_age} * N_at_age_SD24_2005$$

The proportion of immigrants at age from SD 22 (and SD 23) in SD 24 ***prop_fish_SD22_to_SD24*** are computed from the 2005 baseline year percentage (Table 12) as follows:

$$\text{prop_fish_SD2223_in_SD24_in_2005_at_age} = \{0, 0.10+0.03, 0.40+0.02, 0.43+0.06, 0.44+0.02, 0.48+0.04, 0.25+0.25, 0.50+0\}$$

$$\text{prop_fish_SD22_to_SD24} = \frac{(\text{prop_fish_SD2223_in_SD24_in_2005_at_age} * N_at_age_SD24_2005)}{(N_at_age_SD22_2005 + ((\text{prop_fish_SD2223_in_SD24_in_2005_at_age} * N_at_age_SD24_2005))}$$

Proportion of fish that remains in SD 24 ***prop_fish_SD24_to_SD24*** is then:

$$\text{prop_fish_SD24_in_SD24_in_2005} = 1 - (\text{prop_fish_SD2223_in_SD24_in_2005_at_age} + \text{prop_fish_East_in_SD24_in_2005_at_age})$$

$$\text{prop_fish_SD24_to_SD24} = \text{prop_fish_SD24_in_SD24_in_2005}$$

It is assumed that the fish moving from SD 22 and from East to SD 24 stay there. An increase in the number of eastern cod in the western population ('enhanced migration'), in particular for the older ages, is supposed to have occurred from 2008 onward (ICES, 2012). To estimate the change from 2005 to 2011, the absolute numbers of incomers at age (***fish_East_to_SD24_2011***) are calculated from the proportion of eastern cod observed in the SD 24 area in 2011 (similar to 2005):

$$\text{prop_fish_East_in_SD24_in_2011} = \{0, 0.19, 0.67, 0.24, 0.24, 0.38, 0.40, 0.65\}$$

$$\text{fish_East_to_SD24_2011} = \text{prop_migrants_East_in_SD24_in_2011} * N24_2011$$

Table 11: Absolute numbers of East cod in the SD 24 (occurring each year) deduced from the proportion of fish in SD 24 in 2005 and 2011.

	N0	N1	N2	N3	N4	N5	N6	N7
fish_East_to_SD24_2005	0.00000	7290.07267	8594.91778	1247.91115	498.08298	78.16111	0.00000	0.00000
fish_East_to_SD24_2011	0.00000	5373.68296	15222.38671	4815.92611	1484.57475	673.65356	171.55592	118.22825

Table 12: Proportion of immigrant fish from SD 22 in SD24 (occurring each year).

	N0	N1	N2	N3	N4	N5	N6	N7
prop_fish_SD22_to_SD24	0.00000	0.39164	0.38521	0.47982	0.23678	0.38038	0.37392	0.34431

Table 13: Number of sampled fish from SD 24 and percentages of area (subdivision) specific otolith types for these fish as deduced from the otolith shape based assignments. The * fill in the gap for the 2005 value for age 1 assuming *status quo*.

year	age	n	22	23	24	25
2005	1	31	10	3	68	19
	2	392	40	2	32	26
	3	86	43	6	26	26
	4	55	44	2	27	27
	5	23	48	4	26	22
	6	4	25	25	50	0
	7	2	50	0	50	0
2011	1					19*
	2	3	0	0	33	67
	3	140	27	1	47	24
	4	250	36	1	39	24
	5	152	25	3	35	38
	6	83	36	1	23	40
	7	40	23	3	10	65

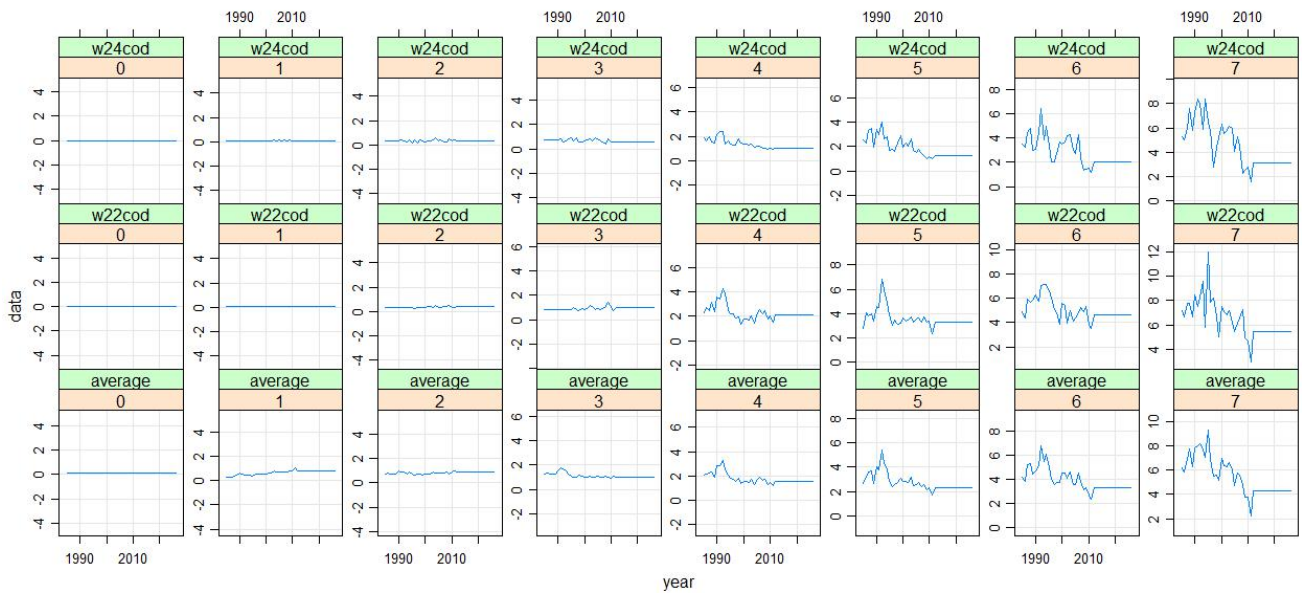


Figure 28. Mean weight-at-age (MWA) for respectively SD 24 cod, SD 22 cod, and an average for SD 24 and SD 22 during the period 1985-2020. The MWA for the period 2011-2020 is estimated as an average of the last 6 years from 2011 backwards.

Preliminary results have shown that the MWA is a critical factor for the results in the projections. When using the SD-specific MWA it is causing the failure of the MSE (i.e. no numerical solution found for the Fs to catch the TACs). Accordingly, in the present simulation (except for one scenario) it was then assumed that the weight at age is not specific to the SD but constitute an average over both areas which is applied both for SD22 and SD24. MWA is generally higher in SD22 and lower in SD24.

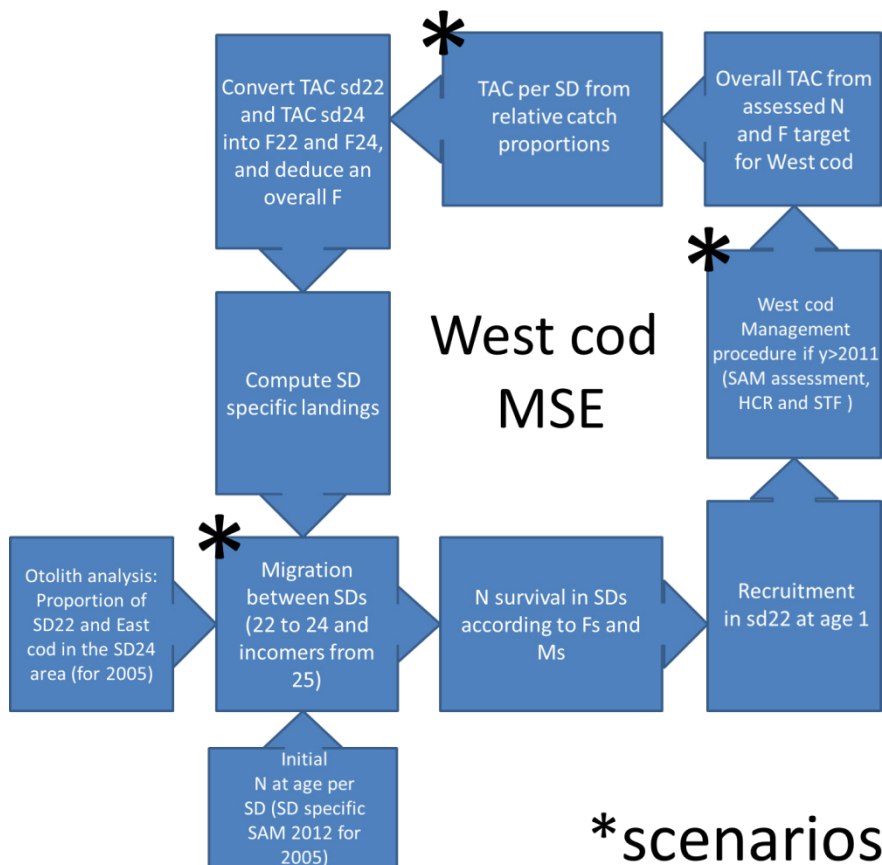


Figure 29. Overview of the model of the West Baltic cod management strategy evaluation. Scenarios are included and evaluated in specific steps of the time loop indicated with asterisks.

The whole MSE and its procedures are described schematically in Figure 29. The scenarios evaluated in the specific processes and steps of the flow are given in Table 2, and cover the following:

- Scenarios 1, 3, 7 and 8 that use the baseline ‘status quo’ migration rates (2005 situation) vs. Scenarios 4, 5, 6, 9, and 10 with enhanced migration rates from 2008 onwards (2011 situation) from the East;
- Scenarios 6, 8 with the relative catch proportion in SD 22 more important (i.e. 0.5 both in SD 22 and SD24) than the 2011 historic one (0.36) vs. Scenarios 5, 7, 9, and 10 with less important proportion in SD 22(0.2 in SD 22 and 0.8 in SD 24);
- Scenario e.g. 1 with the TAC constraint at 15% vs. Scenario 4 with constraint at 30%;
- Scenarios 9 and 10 with implementation error vs. other scenarios without;
- Scenario 10 with MWA from SD 22 vs. other scenarios with average MWA

Table 14: Scenario evaluation specifications for simulations with 100 iterations each

Scenario 1	Baseline ‘status quo’ migration rates +/- 15% TAC constraints
Scenario 2	Enhanced migration rates from 2008 from the East +/- 15% TAC constraints
Scenario 3	Baseline ‘status quo’ migration rates and +/- 30% TAC constraints
Scenario 4	Enhanced migration rates from 2008 from the East and +/- 30% TAC constraints
Scenario 5	Enhanced migration rates from 2008 from the East and decreased catch proportion in sd22
Scenario 6	Enhanced migration rates from 2008 from the East and increased catch proportion in sd22
Scenario 7	Baseline ‘status quo’ migration rates and decreased catch proportion in sd22
Scenario 8	Baseline ‘status quo’ migration rates and increased catch proportion in sd22
Scenario 9	Enhanced migration rates from 2008 from the East, less fishing in SD 22, and implementation error with CV at 0.3
Scenario 10	Enhanced migration rates from 2008 from the East, less fishing in SD 22, and implementation error with CV at 0.3 and Weight-at-age from the SD 22

6.3 RESULTS

There were performed 100 iterations in the simulation of each scenario in the model, i.e. 100 stochastic stocks were simulated per scenario. The stochastic variations arise from the stochastic SSB-R relationships (process error) and from the propagated effect of the observation error on the declared landings originated from the management procedure. Possible implementation error, i.e. when landings overshoot or undershoot the TAC, is not accounted for in the simulations, except for the Scenarios 9 and 10.

The period 2006-2011 is a validation period in relation to the simulations since the management procedure is not yet active in this period, and the successive TACs are the official historical ones here. We observe that the conversion of the TAC into SD specific F_s lead to landings that equal the TAC as expected. Accordingly, the simulated F_s are very similar to the historically assessed ones (estimated by the SAM assessment model) during this period. Also, the drop of the F_{bar} toward lower values in recent years is rather similar to what the stock assessment model concludes (Figure 30).

A systematic comparison of the scenario evaluation outcomes on the stock indicators (R at age 1, SSB, Landings, $F(3-6)$) is conducted by aligning the OM dynamics side by side and accordingly

compare the outputs. Summary probability plots for reaching reference sustainability levels in SSB and in F(3-6) according to the long term management plan (at least for the F) and the MSY approach are also provided.

The MP is able to track the OM dynamics for the baseline scenario (scenario 1), at the scale of the full western Baltic cod stock (SD 22 + SD 24) as well as the dynamics of the two sub-stocks (Figure 30).

Compared to the baseline OM dynamics, the enhanced migration scenario with more incoming cod from the eastern Baltic lead to higher landings from the higher SSB and, accordingly, to a lower global F (Figure 31, scenario 2), the recruitment being equal.

The higher landings from the enhanced migration scenario are actually occurring mainly in SD 24 where the large numbers of eastern cod incomers lower the level of F (Figure 32b). By contrast, higher advised TACs put some pressure on the SD 22 sub-stock which lead to higher F in this area (Figure 32a). The resulting F level in SD 22 is, however, comparable to historical levels.

When changing the year to year long term plan TAC constraint from +/- 15% to +/- 30 % there is a minor effect on the baseline migration situation leading to almost identical OM trajectories (Figure 33 and Figure 34).

The effect of decreasing the proportion of catches from SD 22 compared to the baseline situation (Figure 35) is an increase in the total landings at the global scale, an increase in the SSB, and a lower final F level. This is because the harvesting pressure is relaxed on the SD 22 stock while making more use of the SD 24 sub-stock (Figure 35a). The recruitment, which only occurs in SD 22 in the simulations, is not affected by the scenario since the SSB is already above the 10kt threshold in SSB in the baseline (SSB-R-relationship).

The effect of increasing the proportion of catches from SD 22, compared to the baseline migration situation, is the reciprocal effect of the previous scenario, and lead to increase in the final net F level (Figure 36).

In the situation of enhanced migration, less fishing in the SD 22 subarea will lead to higher landings and lower final F at the global scale based on the higher level of SSB (Figure 38). This is in agreement with the Figure R.5 outcome.

A higher proportion of catch taken in SD 22 in an enhanced migration situation will lead to lower SSB while the landings and F levels are comparable (Figure 39).

The implementation error (scenario 9) adds uncertainties in the final stock status, the final range being wider for the SSB and F indicators (Figure 40) than for the comparable scenario 5. The error (at least at CV=0.3), however, does not propagate to the point that the long term plan is put at risk.

The weights at age are certainly sensitive parameters when running the MSE and for the outcome of the evaluations as the simulations indicates (Figure 41). The SSB is lower and the F higher when the weight at age from SD22 is applied to all western cod but remain within acceptable limits

(Scenario 10, Figure 41). The result from this scenario evaluation can be considered conservative because SD 24 cod are observed smaller than assumed in the scenario.

The probability of getting a high level of $SSB > 60kt$ increase on the short term before decreasing again in the longer term (Figure 42) for all scenarios evaluated, except for scenario 7 (Figure 42e), i.e. where there is less fishing in SD 22 in an enhanced migration situation which overall maintain a high level over the longer time span.

The probability (risk) of obtaining a higher F -level than the target F , i.e. $F > 0.6$, for all scenarios evaluated decreases to low level on the short term level before increasing again at the long term horizon (Figure 43). The probability (risk) to exceed $F > 1.0$ remains low over time for all the scenarios.

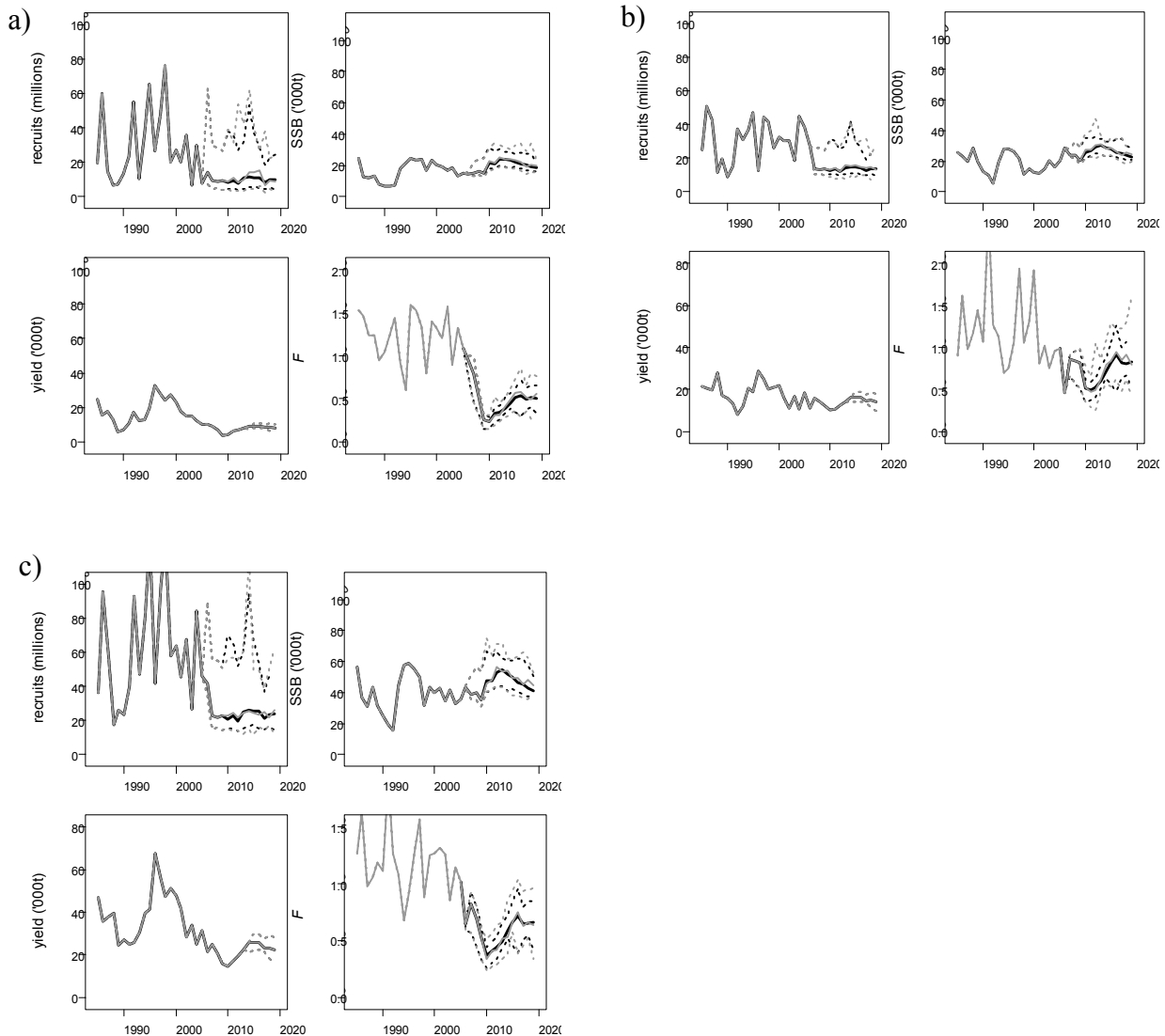


Figure 30. Baseline “status quo” migration rates (scenario 1) with a) w22cod, b) w24cod, c) w22-24cod. OM stocks in black, MP ‘perceived’ stocks in grey.

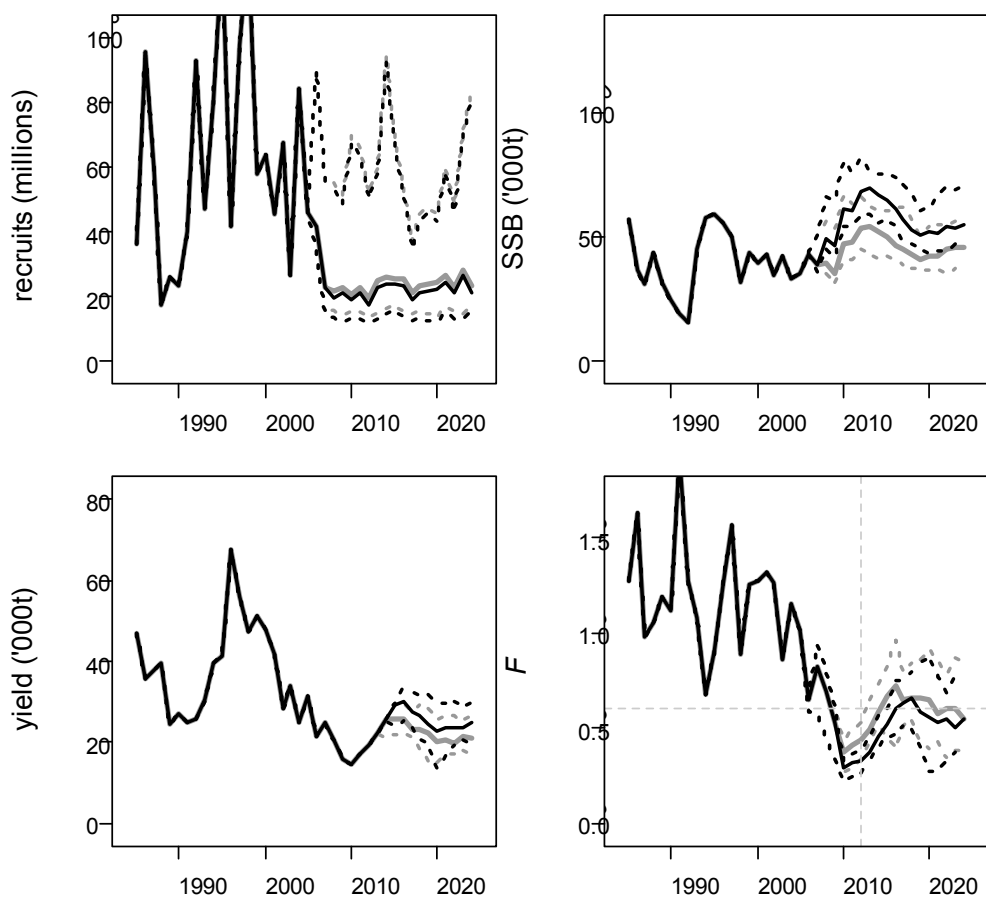


Figure 31. OM scenario 1 stock trajectories (grey) vs. OM scenario 2 (black). Respective 5-95% percentiles given in dotted lines.

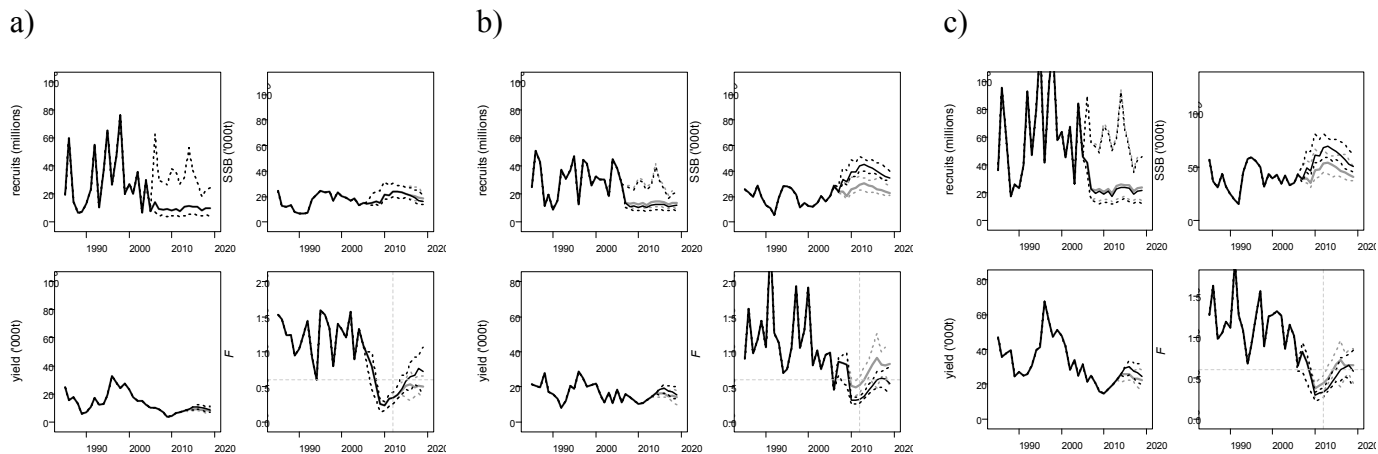


Figure 32. OM scenario 1 (baseline, in grey) vs. OM scenario 2 (enhanced migration scenario, in black) for a) w22cod, b) w24cod, c) w22-24cod.

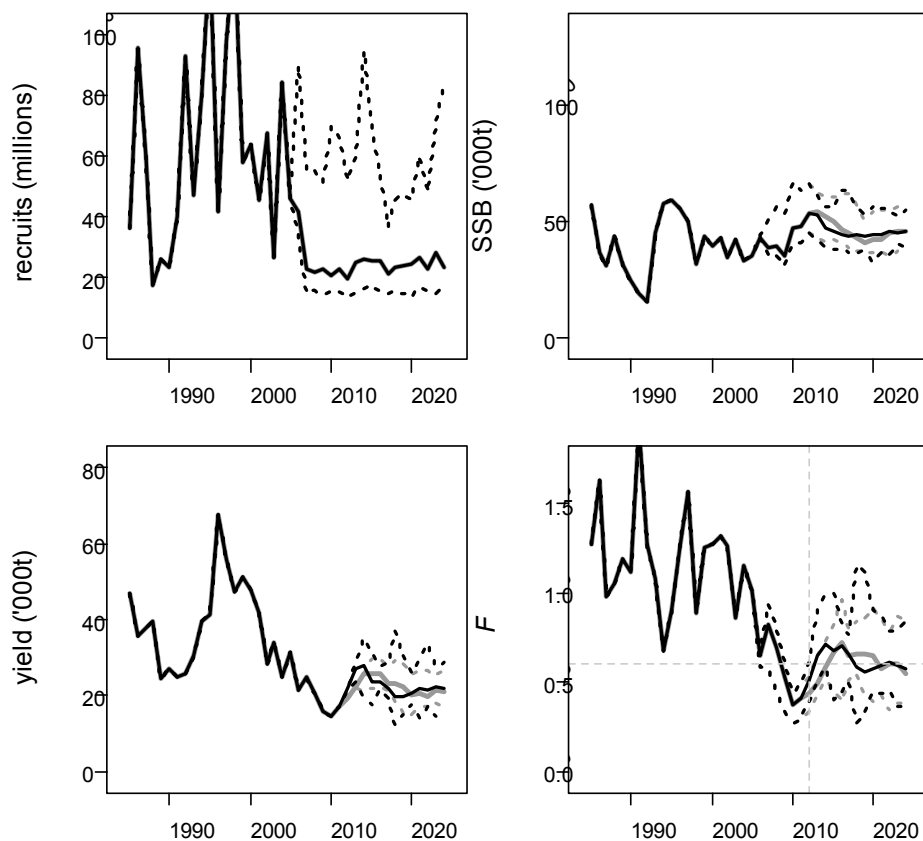


Figure 33. OM scenario 1 (baseline, in grey) vs. OM scenario3 (TAC 30%, in black). Respective 5-95% percentiles given in dotted lines.

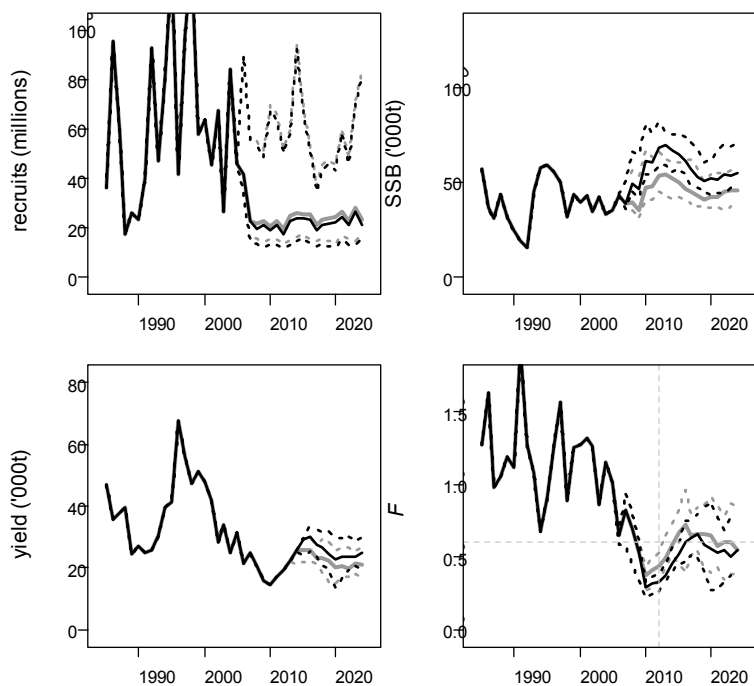


Figure 34. OM scenario 2 (enhanced migration, in grey) vs. OM scenario 4 (TAC 30%, in black). Respective 5-95% percentiles given in dotted lines.

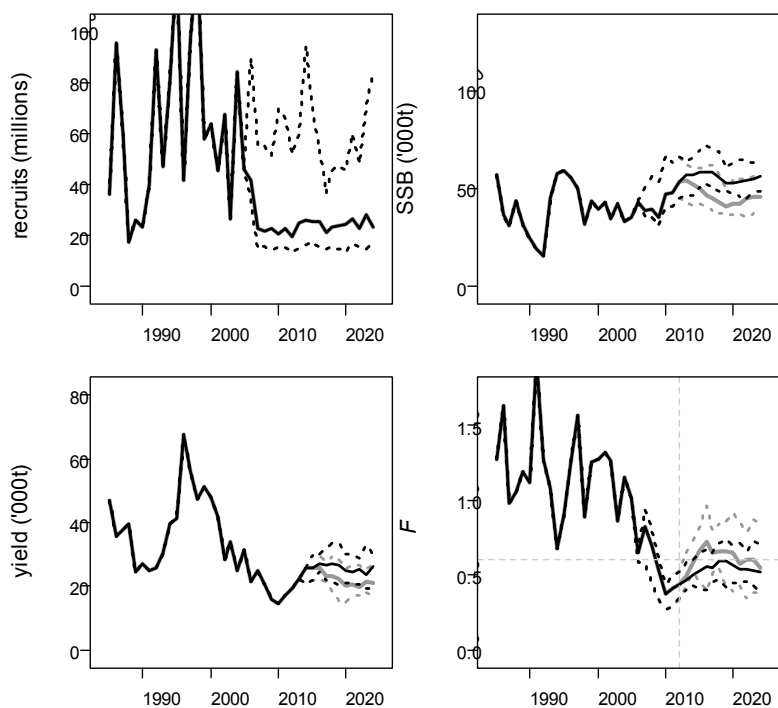


Figure 35. OM scenario 1 (baseline, in grey) vs. OM scenario 8 (less fishing in sd22, in black). Respective 5-95% percentiles given in dotted lines.

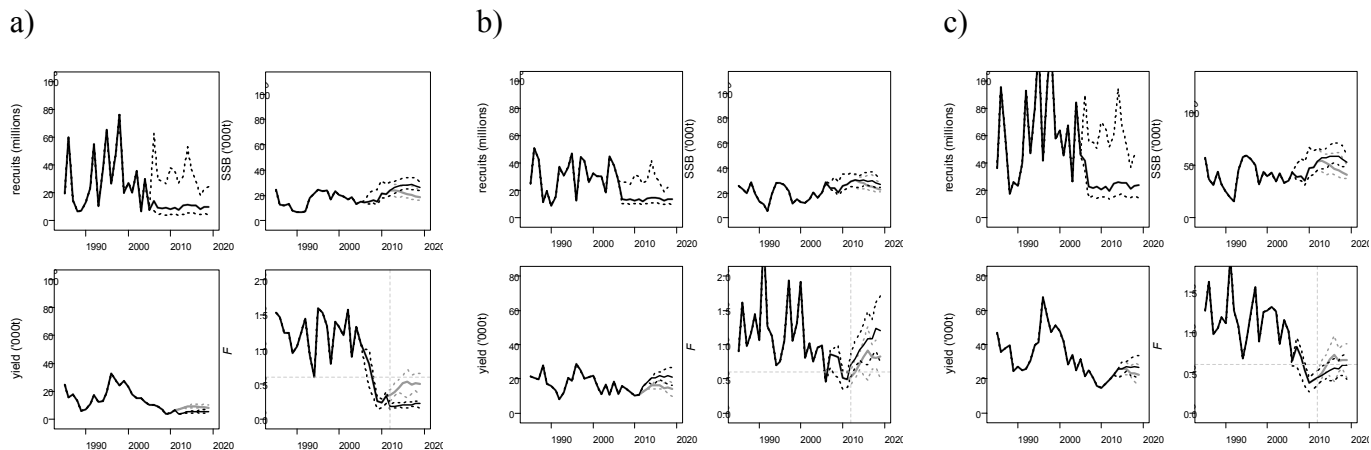


Figure 36. OM scenario 1 (baseline, in grey) vs. OM scenario 8 (less fishing in sd22, in black) for a) w22cod, b) w24cod, c) w22-24cod.

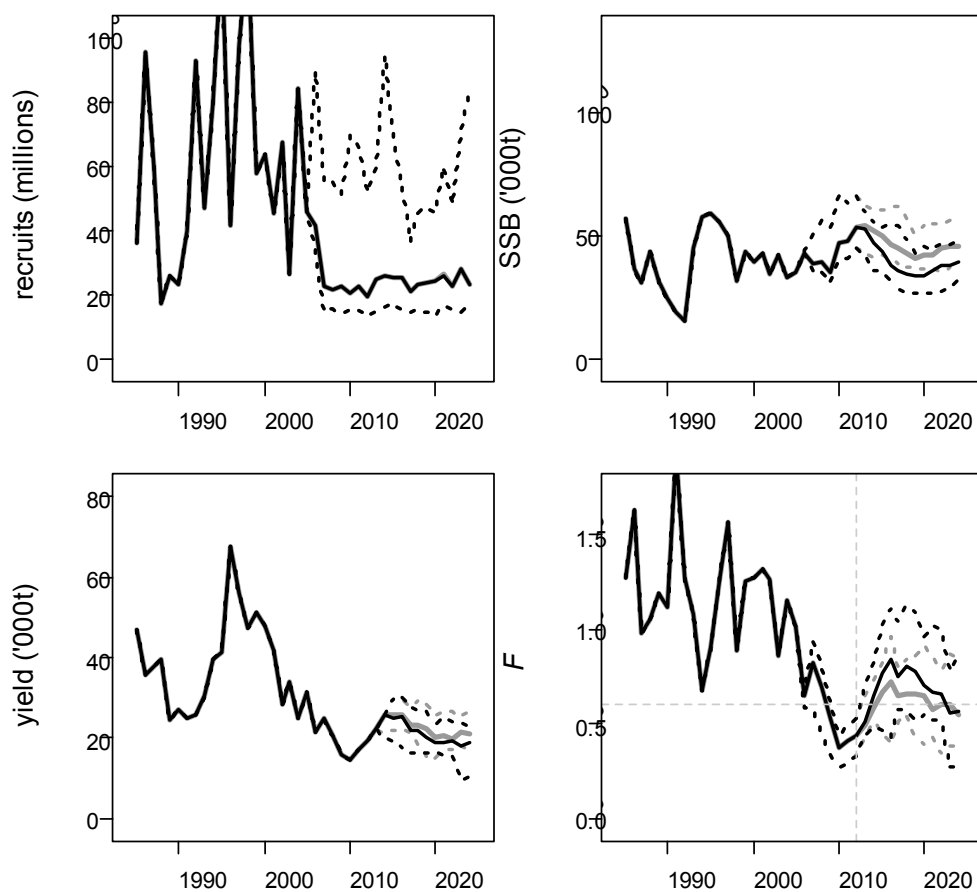


Figure 37. OM scenario 1 (baseline, in grey) vs. OM scenario 7 (more fishing in sd22 OM, in black). Respective 5-95% percentiles given in dotted lines.

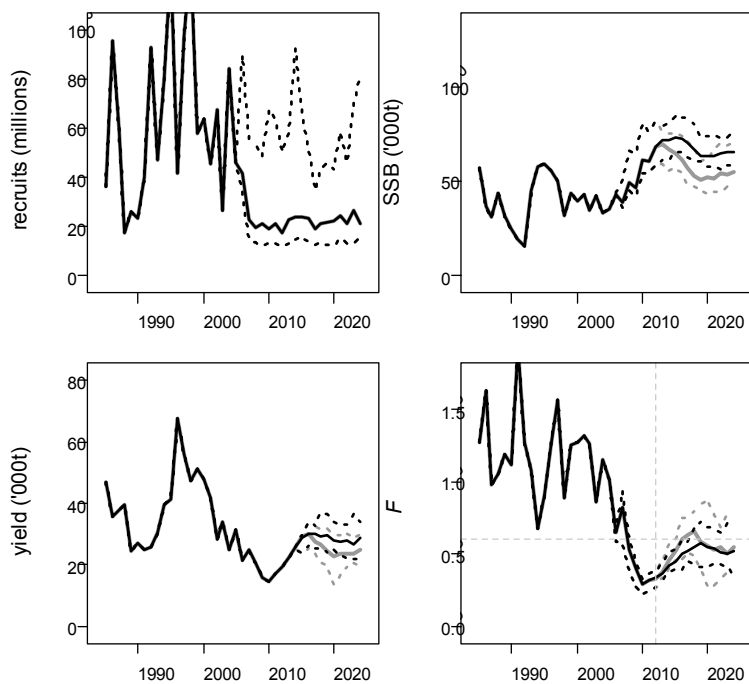


Figure 38. OM scenario 2 (Enhanced migration from East, in grey) vs. OM scenario 5 (less fishing in sd22in black). Respective 5-95% percentiles given in dotted lines.

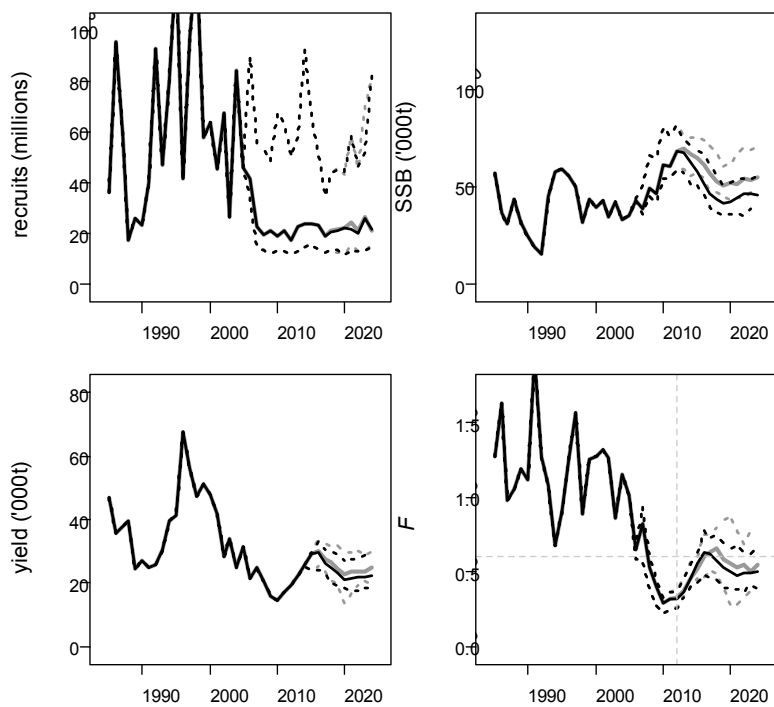


Figure 39. OM scenario 2 (enhanced migration from East, in grey) vs. OM scenario 6 (more fishing in sd22, in black). Respective 5-95% percentiles given in dotted lines.

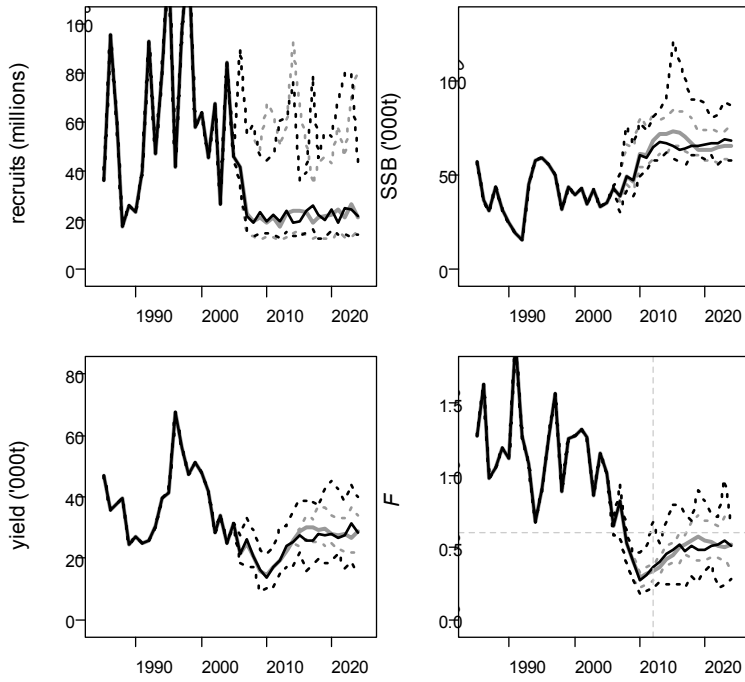


Figure 40. OM scenario 5 (enhanced migration from East and less fishing in sd22, in grey) vs. the OM scenario 9 (same but with an implementation error at CV=0.3, in black). Respective 5-95% percentiles given in dotted lines.

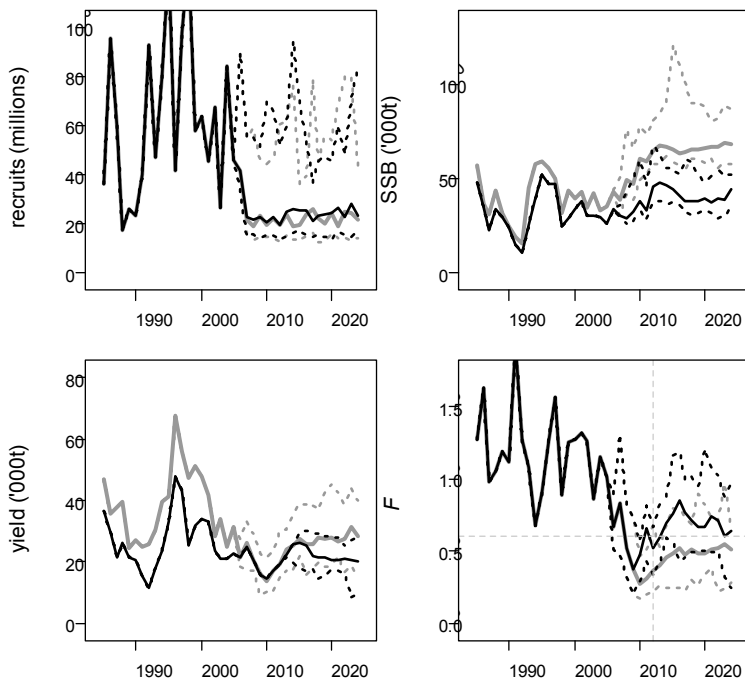


Figure 41. OM scenario 9 (enhanced migration from East and less fishing in sd22 and with an implementation error at CV=0.3, in grey) vs. OM scenario 10 (the same but with weight at age from SD 22 for all, in black). Respective 5-95% percentiles given in dotted lines.

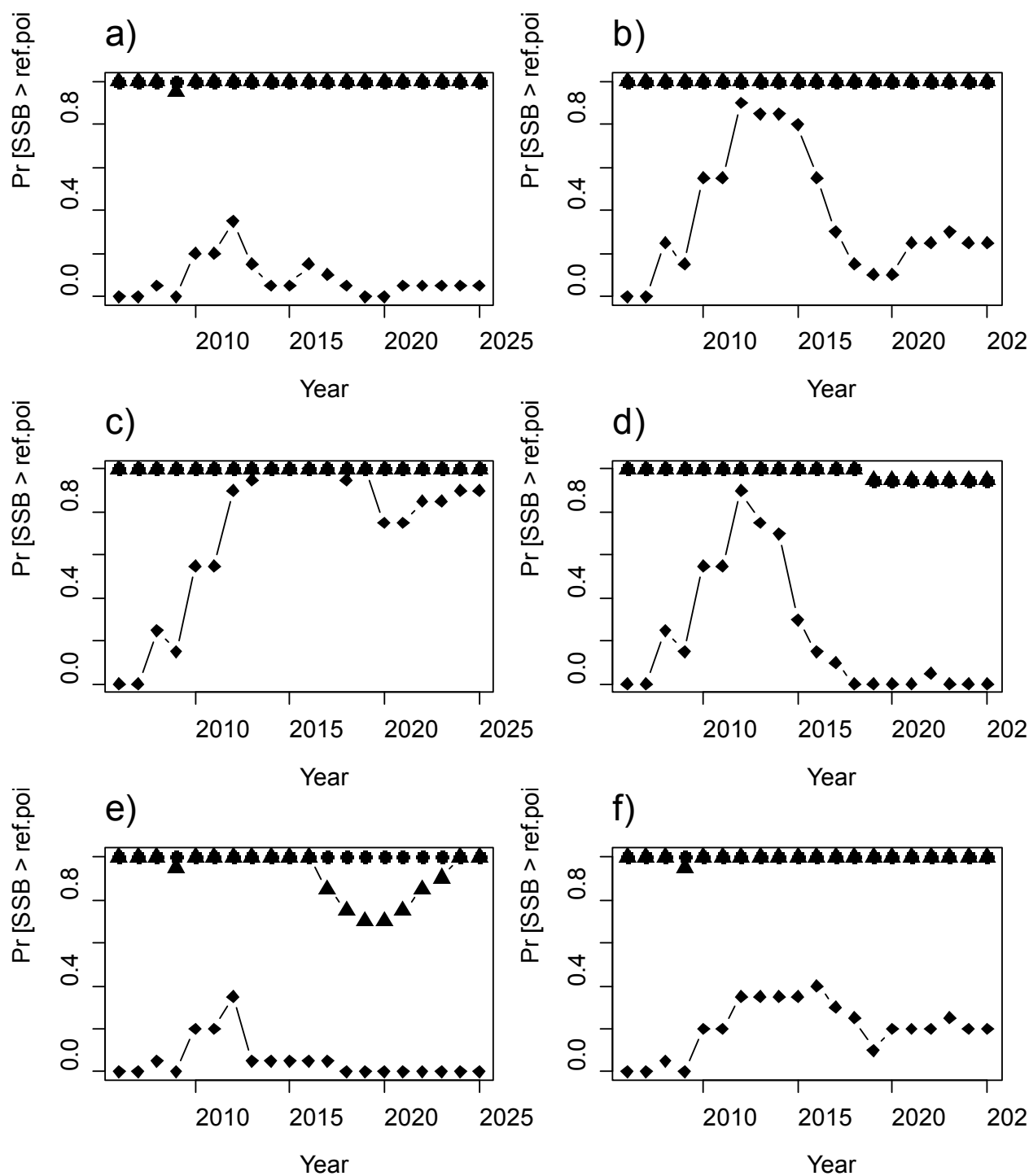


Figure 42. Probabilities to be above sustainability reference levels set in the LTMP of West (SD22-24) cod SSB over years for 6 selected scenarios a) to f) corresponding to scenarios 1, 2, 5, 6, 7, 8 (see Table 14). circle: SSB>10kt; triangle: SSB>30kt; diamond: SSB>60kt

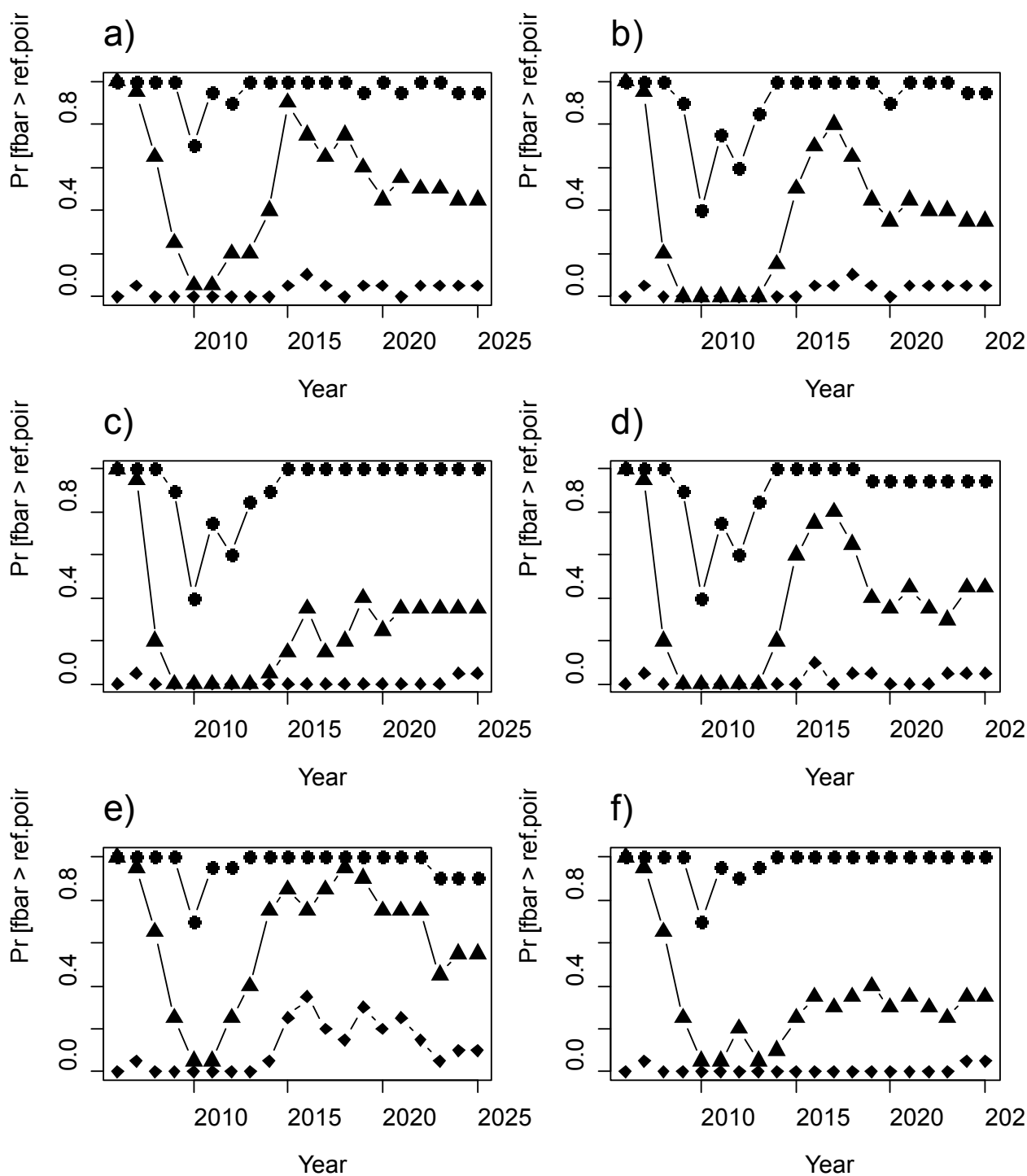


Figure 43. Probabilities to be above some reference levels of West cod fishing mortality $F_{\text{bar}}(3-6)$ for 6 selected scenarios a) to f) corresponding to scenarios 1, 2, 5, 6, 7, 8 (see Table 14). circle: $F(3-6)>0.3$; triangle: $F(3-6)>0.6$; diamond: $F(3-6)>1.0$

6.4 CONCLUSIONS

- Given the currently implemented F under the long-term cod management plan, the target level of $F < 0.6$ hereunder is achievable within all the tested scenarios with different levels of mixing and area proportions for fishing pressures, even in a low regime situation for recruitment, and with observation error when evaluating the stock status and with implementation error in relation to the advised TACs. The different scenarios results in different stock levels respectively on the short term and long term scale.
- The main message is that the migrants (incomers) from East to SD24 lead the management procedure to advice for higher TACs that put some pressure on the F level in SD22. The F level in SD22 in this situation will need to be slightly lowered and this may be done by allocating more effort and catch to the SD 24 area from SD22. Higher landings are expected if effort is re-directed/re-allocated to the SD 24 subarea making profit of the eastern cod incomers. By lowering the F in SD 22, the SSB in SD 22 is also preserved, which is assumed to be the origin of recruits for the whole West cod (i.e. SD 22 + SD 24), as assumed in most of the tested scenarios. This is also assuming that there is not back migration of fish from SD 24 to SD 22 that would lower the cod abundance in SD 24 (but increase SSB in SD 22).
- Unforeseen uncertainties can, however, affect the performance of the management plan. A first unknown is the effect of difference in weight-at-age between areas / sub-division. The weight-at age has been averaged between SD 22 and SD 24 in most of the simulations because the MSE fails otherwise. The SD 22 cod have higher condition and MWA compared to SD 24. In this situation the N is overestimated for SD 22 and underestimated for SD 24.
- Furthermore, additional information and data are needed to better inform the model on the area specific stock mixing and migration rates of cod between western Baltic sub-areas/sub-divisions and from the East to SD24. Currently the net migration rates are based on proportion of fish per area based on otolith shape analysis. Genetic studies (or tagging experiments) needs to be integrated more in order to inform better and refine the simulations by providing more well documented migration rates instead of net migration rates based on this limited data (material based on otolith shape analyses on a material sampled over only 2 years and in one sub-division SD24).
- Another investigation to carry out is to obtain better knowledge on and deeper understanding of the processes associated to location of the spawning grounds and potential shifts over time herein. That is for example to get a better understanding of recruitment to the different sub-area populations from spawning in different areas, as well as in this context also to obtain knowledge on whether some of the SD22 cod migrating to SD24 actually returns (fully or partly) to SD22 to spawn. Also, this included needs for increased knowledge on whether the East (SD 25) incomers actually spawn in SD24, or just stay there, or returns to the East (SD25) to spawn. So far, no spawning events are assumed to occur in SD24 in relation to the MSE. Spawning events has, however, to limited extent been observed in SD 24 (Arkona basin). However, it is assumed that the cod spawning in the

Arkona Basin in SD24 only originate from immigrants of East cod, and they do not contribute to the western Baltic cod recruitment.

- These model uncertainties and limitations in data and knowledge basis in relation to the MSE can affect very much the results and accordingly the recommendations for management. The direction the system will turn in relation to these uncertainties is currently difficult to foresee.

Milestones:

M6. Establishment of a new stock assessment model that incorporates migration and variable stock mixing of several stocks (November 2012)

M7. Consequence estimation of different management scenarios under the revised management plan (Fmsy) based on variable geographic distribution and stock mixing (November 2012)

Status: *Accomplished*

7. MANAGEMENT IMPLICATIONS

MONITORING SYSTEM

Results from this study have identified genetic profiling as a highly powerful approach for individual assignment and estimation of mixing proportions of cod in the Baltic Sea, while otolith shape analysis provides additional information on the area inhabited by an individual. The combined use of genetics and otolith shape analysis thus proved to be a useful tool to study migration and stock mixing dynamics in the Baltic Sea. Since genetic and otolith shape analyses are possible with historical material (e.g. archived otoliths and DNA extracted from the otoliths), these analyses can also be extended backwards in time. This study has documented substantial and temporally variable immigration of “Eastern” cod into SD 24 with ensuing implications for stock assessment and management, thereby highlighting the need for an effective monitoring system. We propose to expand routine sample collections to include genotyping and image analysis of otolith shapes for monitoring of stock dynamics with a high spatio-temporal resolution. The analytical tools to undertake the subsequent estimation of mixing proportions are already available, but the interpretation of otolith shapes needs further refinement before methods can be optimally used in conjunction.

EFFECT OF STOCK MIXING ON THE EASTERN BALTIC COD STOCK

Due to substantially higher stock size of cod in SD 25-32 compared to that observed in SD 22-24, the possible magnitudes of cod of eastern origin moving over to the western Baltic Sea is not expected to pose risks to the status of the eastern Baltic cod. However, the potential contribution of spawning taking place in the Arkona Basin to the recruitment of the eastern Baltic cod is currently unknown.

RISK OF LOCAL DEPLETION OF THE WESTERN COD STOCK

The abundance of adult cod is currently low in SD 22, while targeted cod fishery is taking place in this area in the first quarter of a year, i.e. during the spawning period in SD 22. The cod spawning in SD 22 represent true western Baltic population, and the stock size in this area shows close correspondence to recruitment in the entire western Baltic area (SD 22-24). Thus, the stock component in SD 22 needs further protection to enhance the western Baltic cod population.

MANAGEMENT AREAS

Cod dynamics in SD 24 has followed that in SD 25 in the entire available time series since the 1980s, indicating close association between the sub-populations in these areas. Nevertheless, changing management areas, e.g. joining the entire SD 24 with the eastern Baltic cod management area may not be appropriate. This is because SD 24 is considered to consist of cod of both western (SD 22) and eastern (SD 25) origin. However, in situations of pronounced differences in stock sizes in SD 22 and 24 (which is the case at present), additional area specific management measures should be applied. Further, the stock assessment for western Baltic cod (SD 22-24) is currently likely biased by the exchange of adult cod between the eastern and western Baltic management areas, that produce large geographical and inter-annual variability in stock indices, and consequently uncertain estimates of fishing mortality particularly for older ages

QUANTITATIVE SPLIT OF STOCK DATA

Splitting and explicitly taking into account the eastern component of the cod found in the western Baltic area in the assessment and subsequently in the management would be necessary, if the cod moving in to the western Baltic area are not permanently staying and contributing to the reproduction in this area. Therefore, it is crucial to improve the understanding of recruitment dynamics in the western Baltic area, in particular whether the cod of eastern origin moving to the western Baltic area produces viable offspring that contributes to the stock in the western Baltic area. This is currently not known.

REFERENCE POINTS

The current biological reference points are based on observed stock recruitment relationships in the entire western Baltic area (SD 22-24). However, there are indications that the recruitment in the western Baltic area depends on the abundance of local spawning populations (in SD 22). Therefore, developing area specific biomass reference points may be more appropriate.

MANAGEMENT STRATEGIES

Tools are available to evaluate management strategies under different levels of migration within and between management areas. However, these results are conditional of the knowledge about annual migration rates and whether a return migration is taking place. Further, knowledge of the contribution of spawning grounds in SD 22 and 24 to recruitment of different sub-populations is essential.

8. FUTURE RECOMMENDATIONS

In order for the presented suit of approaches from sample to management plan evaluation to be fully operational additional information is needed. In this study, information on a number of issues were found to be suboptimal, including lack of spatio-temporal resolution of the two stock' spawning areas and recruitment dynamics as well long term migration dynamics of adults. These issues are elaborated below, including comprehensive solutions.

SPAWNING AREAS

The genotyping of spawning individuals has documented that both “Western” and “Eastern” cod spawn in SD 24. As these results are based on a rather limited number of “Western” cod and the fact that their exact catch location is not known, these results cannot be used quantitatively. However, they indicate that a mapping of spawning components within SD 24 with a high spatial and temporal resolution is essential in order to gain the necessary insight into the spawning dynamics in that SD.

Solution: Collecting information on the occurrence of spawning individuals for each commercial trip (high temporal resolution covering entire years) attended by scientific Observers or fishermen and combining this mapping of area-specific spawning activity with genotyping of individual fish.

RECRUITMENT

Despite the considerable immigration of “Eastern” cod into SD 24 and were observed to spawn in that area, recruitment of the “Western” stock (Figure 2) has not increased concurrently. This suggests that the “Eastern” immigrants may not contribute to the recruitment of the “Western” stock. Alternatively, the recruits in SD 22-24 consist primarily of “Eastern” cod as a consequence of an extremely low recruitment of the true “Western” stock.

Solution: Genotyping of juveniles from all relevant SD's and stock components could resolve this issue, both in the form of future samplings as well as analysis of archived samples to establish a suitable time series. As stock assessment heavily depends on the use of reliable stock-recruitment relationships, resolving this uncertainty is considered a key issue for future work.

MIGRATION DYNAMICS

In the simulations carried out in this study it was assumed that fish migrating from the “Eastern” to “Western” stock stay there. The comparative analysis of otolith shape-based assignment with genotype indicated that this may not be the case, i.e. a proportion of cod may stay, while others may

return to their original area. With the data available from this study it was not possible to quantify the different behavior strategies. As these migration strategies have direct consequences for the management of the “Western” stock, further research into the migration dynamics in the area is needed. Furthermore, the results from this study showed that within the same trawl haul a mixture of “Eastern” and “Western” cod occurred, and that the composition of the two stock components varied within SD 24. This suggests that the mixing of the two stocks is subject to a spatial gradient from east to west. Further examination into these dynamics, based on the studies suggested below will provide the necessary data for this information to be included in the stock management.

Solution: A number of techniques and data are available to fulfil the requirements for this task: 1) Analysis of tag data from cod marked with electronic data storage tags (data and genetic samples of the tagged fish available at DTU Aqua), 2) Comparative analyses with genetics and otolith shape targeting this issue specifically, 3) Analyse the microchemistry composition of otoliths for the area-specific signals in trace element concentrations on a seasonal basis over the fish’s entire life (also in historic samples) and 4) analysis of isotope- and lipid composition of fish to reveal area-specific feeding history

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Colophon

Improved management based on stock identification of eastern and western Baltic cod

By Karin Hüsey, Francois Bastardie, Margit Eero, Jakob Hemmer-Hansen, Henrik Mosegaard and J. Rasmus Nielsen

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